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BIOLOGICAL SCIENCES

FLORISTIC AND ECOLOGICAL FEATURES OF STONY AND GRAVEL VEGETATION IN THE MOUNTAIN AREAS OF AZERBAIJAN REPUBLIC

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Abstract

This study investigates the floristic composition, ecological characteristics, and conservation significance of stony-rocky and gravelly vegetation in the high-mountain regions of Azerbaijan, including the Greater and Lesser Caucasus and the Nakhchivan Autonomous Republic. Petrophilic plant communities, though relatively poor in species richness, play a crucial role in soil formation, moisture retention, and the stability of mountain ecosystems. The research highlights the importance of pioneer species such as mosses and lichens in initiating vegetation cover, followed by the establishment of higher spore-bearing and flowering plants. Endemic species of the Caucasus, particularly within the Campanulaceae family, were identified as key representatives of rocky vegetation, underscoring their strategic role in maintaining genetic diversity and ecological resilience. Comparative analysis of different altitudinal zones revealed distinct phytocoenotic structures shaped by substrate composition and microclimatic conditions. The findings emphasize the necessity of continuous monitoring, ecological restoration, and protective measures to prevent degradation of these fragile ecosystems and to safeguard their biodiversity.

Keywords: Azerbaijan flora, Rocky and gravelly vegetation, Petrophilic phytocoenosis, *Campanulaceae* Juss., Endemic species, Mountain ecosystems, Biodiversity conservation, Nakhchivan Autonomous Republic

1. INTRODUCTION

Recent studies demonstrate that, the condition of flora and phytocoenoses across Azerbaijan's diverse ecological regions is closely linked to anthropogenic pressures, soil salinity, and industrial pollution. The degradation of arid forests, the transformation of phytocoenoses along the Kura River, and the oil-contaminated soils of the Absheron Peninsula vividly illustrate the scale of these impacts. Furthermore, the spread of pathogenic fungi in plants and their ability to secrete hydrolytic enzymes pose additional risks to agricultural productivity and ecological health. Taken together, these findings underscore that the resilience of Azerbaijan's flora and phytocoenoses can only be ensured through strengthened ecological monitoring, systematic implementation of conservation measures, and the protection of biological diversity *(Togola, A. & 2023; Mammadova F., 2024, 2025; Gurbanov E.M., & 2022, Jafarzadeh, S.A., & 2022; Mammadova, Z.J., &, 2016; Mammadova Z.J., 2017, Mammadova Z., 2024; Eyubov B.B., 2009; Gurbanov E.M., &, 2024, Gurbanov, E.M, 2019; Gurbanov E.M., & 2021; Gurbanov E.M. &, 2023).*

The stony-rocky and gravelly rocky vegetation formed in the high mountainous areas of Azerbaijan Republic is one of the most important components of the country's phytocenosis diversity. This vegetation cover is widespread in both the Greater and Lesser Caucasus mountains, as well as in the mountainous zones of the Nakhchivan Autonomous Republic. The study of rocky vegetation is of great importance not only for botanical science, but also in terms of protecting ecological stability. Because these plants play a key role in the process of soil formation, moisture retention and the sustainability of mountain ecosystems.

In historical sources, the studies of A.G. Dolukhanov (1932), A.A. Grossheim (1948), L.I. Prilipko (1970), V.J. Hajiyev (2004), E.M. Gurbanov (2007, 2009) and other scientists have extensively illuminated the species composition, distribution area and ecological characteristics of rocky vegetation *(Dolukhanov, A.G., 1932; Grossgeim, A.A., 1948; Gurbanov, E.M, 2007; Gurbanov E.M, 2009; Hajiyev V.C, 2004; Prilipko, L.I., 1970).* Their research shows that; rocky vegetation has unique characteristics both from a floristic and phytocenological point of view. The distribution of these plants depends on altitudinal zones, rock composition and local climatic conditions.

The formation of rocky vegetation begins with the role of "pioneers" played by primitive plants – algae, mosses and lichens. At a later stage, the phytocenosis is enriched with the participation of higher spore and flowering plants and the process of soil formation is accelerated. Although the species composition of rocky vegetation is not rich, it performs very important functions from an ecological point of view *(Ibrahimov A.Sh, 2013).*

Endemic species found in rocky ecosystems *Campanula saxifraga* subsp. *meyeriana* (Rupr.) Ogan. = (*Campanula meyeriana* Rupr.), *Saxifraga pontica* Albov, *Draba mollissima* Steven, *Draba incompta* Stev., *Alyssum globosum* Grossh., *Galium vartanii* Grossh., *Galium tianschanicum* M. Pop., *Tanacetum kotschyi*

(Boiss.) Grierson = (*Pyrethrum ordubadense* Manden.), *Tanacetum partheniifolium* (Willd.) Sch. Bip. = (*Pyrethrum kubense* Grossh.) are unique to the Caucasus flora, and the conservation of these endemic species is of strategic importance for the preservation of the region's biological diversity. These endemic species are of strategic importance not only for ecological stability, but also for the preservation of genetic diversity *(Gurbanov E.M., 2009, Nasirova A.S., 2015).*

Thus, the study of rocky vegetation is of strategic importance not only for botanical science, but also for the ecological stability and economic use of mountainous areas. The purpose of this article is to systematically analyze the floristic composition, ecological characteristics and economic importance of the rocky vegetation of Azerbaijan, as well as to provide scientific grounds for their protection and restoration.

2. MATERIAL AND METHODS

The Greater and Lesser Caucasus Mountains of Azerbaijan Republic, as well as the high mountainous areas of the Nakhchivan Autonomous Republic, were selected for the study. During the research, vegetation cover was studied in stony, rocky, and gravelly massifs found in all zones of Azerbaijan. Classical geobotany methods were applied for phytocenological observations, and association and formation groups were determined. The species composition of plants was recorded by visual observation and collection of herbarium specimens on site. The collected specimens were subjected to systematic analysis in laboratory conditions and compared with the existing floristic literature. The ecological characteristics of plants distributed on gravelly and rocky substrates were analyzed based on the predominance of edificatory species. Methodological approaches of local and international botanists were used at all stages of the study *(Dolukhanov, A.G., 1932, Grossgeim A.A., 1948; Gurbanov E.M, 2007; Gurbanov E.M, 2009; Hajiyev, V.C., 2004; Ibrahimov A.Sh., 2013; Ibrahimov, A.Sh., 2005; Prilipko, L.I., 1970).*

3. DISCUSSIONS

Based on the results of the conducted studies, the phytocenological structure, species composition and ecological characteristics of plants found in rocky, stony-rocky and gravelly areas in Azerbaijan reveal a number of important scientific points.

The formation of rocky vegetation begins with the role of "pioneers" played by primitive plants - algae's, mosses and lichens. These plants accelerate the process of soil formation and create conditions for the development of higher spore and flowering plants. As a result, the species composition of the phytocenosis is enriched and the stability of the ecosystem is ensured. In the high mountainous zone, the occurrence of mosses and lichens on stones and rocks such as: *Cladonia* P. Browne, *Cetraria* Ach., *Polytrichum* Hedw., *Thamnolia* Ach. ex Schaerer, etc. have been noted.

In rocky-debris groups, *Saxifraga moschata* Wulfen, *Saxifraga exarata* subsp. *exarata* = (*Saxifraga adenophora* C. Koch), *Campanula petrophila* Rupr., *Campanula tridentata* Schreb., *Campanula saxifraga* subsp. *meyeriana* (Rupr.) Ogan. = (*Campanula meyeriana* Rupr.), *Draba mollissima* Steven, *Draba incompta* Stev., *Draba bruniifolia* Stev., *Draba siliquosa* Bieb., *Alyssum globosum* Grossh., *Galium vartanii* Grossh., *Galium tianschanicum* M. Pop., *Cerastium multiflorum* C.A. Mey., *Alchemilla sericata* Reichenb. ex. Bus., *Alchemilla retinervis* Bus., *Minuartia hirsuta* subsp. *oreina* Mattf. = (*Minuartia oreina* (Mattf.) Schischk and other species are encountered *(Nasirova A.S., 2015; Nasirova A.S. &, 2024; Talibov T.H., 2014).*

On the rocky outcrops of the alpine zone and on the fine soils between the rocks, *Campanula tridentata* Schreb., *Astragalus incertus* Ledeb., *Astragalus psoraloides* Lam. = (*Astragalus gjunaicus* Grossh.), *Saxifraga cartilaginea* Willd., *Festuca ovina* L., *Thymus transcaucasicus* Ronn., *Alchemilla raddeana* (Bus.) Juz., *Potentilla argentea* L., *Draba siliquosa* Bieb., *Pseudovesicaria digitata* (C.A. Mey.) Rupr. and other xerophytes are found. In the shady crevices, the ferns *Dryopteris* Adans., *Athyrium* Roth, *Polypodium* L., *Woodsia* R. Br. species have been recorded.

In the Nakhchivan Autonomous Republic, the rock-debris or petrophyte phytocenosis is widespread in all mountainous belts of the Nakhchivanchay basin on rocks: mosses, *Racomitrium ericoides* Brid., *Grimmia ovalis* (Hedw.) Lindb.; perennial herbs, *Saxifraga pontica* Albov, *Sedum tenellum* Bieb., *Erysimum pulchellum* (Willd.) J. Gay, *Dianthus orientalis* Adams, *Campanula bayerniana* Rupr. etc.; and shrubs, *Cotoneaster integerrimus* Medik., *Rhamnus erythroxyloides* subsp. *erythroxyloides* = (*Rhamnus pallasii* Fisch. et C.A. Mey.), *Ephedra procera* Fisch. et C.A. Mey., and species of the genera *Juniperus* L., *Crataegus* L. and *Rosa* L. have been found by us during the research.

In the composition of stable debris: *Vicia ciceroidea* Boiss., *Anthemis cretica* subsp. *iberica* (M. Bieb.) Grierson= (*Anthemis iberica* Bieb.), *Nepeta supina* subsp. *buschii* Sosn. & Manden. Menitsky = (*Nepeta buschii* Sosn. et Manden.), *Tanacetum kotschyi* (Boiss.) Grierson = (*Pyrethrum kotschyi* Boiss.), *Tanacetum partheniifolium* (Willd.) Sch. Beep. = (*Pyrethrum cubense* Grossh.), *Cirsium isophyllum* (Petr.) Grossh. = (*Cirsium tomentosum* C.A. Mey.), *Jurinea moschus* (Hablitz) Bobrov = (*Jurinella subacaulis* Fisch. et C.A. Mey. Iljin), *Thalictrum sultanabadense* Stapf, *Oxyria digyna* (L.) Hill), *Sibbaldia semiglabra* C.A. Mey. species have been found by us during the study.

The phytocenological characteristics of the representatives of the *Campanulaceae* Juss. family distributed in the flora of Nakhchivan Autonomous Republic were studied and it was determined that, the species of this family are the most characteristic representatives of rocky-petrophilic vegetation types. The author found, that 9 species of the *Campanula* L. genus are distributed in petrophilic vegetation, 7 of which are recorded as petrophilous on shady rocks and cracks, and 2 species are petrophilous on debris and gravel *(Nasirova A.S., 2013; 2015; 2018; 2014; 2015; 2016; 2012; 2017).*

7 species of *Campanulaceae* family [*Campanula karakuschensis* Grossh., *C. coriacea* PH Davis, *C. zangezura* (Lipsky) Kolak et Serdj., *C. sclerotricha* Boiss., *C. bayerniana* Rupr., *C. saxifraga* Bieb., *C. daralaghezica* (Grossh.) Kolak et Serdjukova] have been discovered on shaded rocks and rock crevices as a representative of petrophilic vegetation type. 2 species

of the family [*Campanula massalskyi* Fomin, *C. propinqua* Fisch. et C.A. Mey.] have been found on debris and pebble stones as a petrophilic vegetation type *(Nasirova A.S., 2016; 2013; 2013; 2015; 2016; 2018; 2014; 2020; 2017).*

The rocky, stony-rocky and gravelly flora distributed in the territory of Azerbaijan is very poor in terms of species composition. Mosses, lichens and flowering plants, as well as endemic species, are most often found in the rocks. In order to prevent the degradation process of vegetation cover in the rocky vegetation type formed in the stony-rocky and gravelly zone, phytoecological, rationalization and restoration measures should be regularly carried out.

4. CONCLUSION

The results of studies conducted in the high mountainous areas of Azerbaijan Republic show that, stony-rocky and gravelly vegetation is one of the important components of the country's phytocenosis diversity and plays a strategic role in maintaining ecological stability. Although the overall richness of species found in rocky and gravelly substrates is limited, the high share of endemic and relict species confirms the special importance of these phytocenoses for biological diversity. Representatives of the *Campanulaceae* family were identified by us as the most characteristic elements of petrophilous vegetation types. The formation of rocky vegetation begins with the “pioner” role of primitive algae’s, mosses and lichens, and at a later stage the phytocenosis is enriched with the participation of higher spore and flowering plants. Stony-rocky and gravelly vegetation is an important phytocenosis type that, ensures the stability of the mountain ecosystems of Azerbaijan. Although their floristic composition is limited, the high share of endemic species makes these ecosystems unique in terms of preserving biological and genetic diversity. Therefore, regular monitoring of rocky vegetation, ecological restoration measures, and limitation of anthropogenic impacts should be considered essential for the ecological security of the region.

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DESERT AND SEMI-DESERT PHYTOCENOSES OF THE MIL PLAIN: IMPLICATIONS FOR WINTER PASTURE MANAGEMENT

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Abstract

At the present stage, the efficient use of phytocenoses or vegetation cover of natural winter pastures is of particular relevance. As a result of our research, the phytocenological structure, species composition, productivity, and forage capacity of characteristic formations occurring in various vegetation types of the Mil Plain have been studied. Based on these investigations, recommendations for the rational use and improvement of the studied phytocenoses have been developed.

Keywords: type, formation, association, dominant, subdominant, phytocenosis

Study Area and Methods

Geobotanical studies were conducted in several areas of the Mil Plain, mainly within the administrative boundaries of the Agjabadi District, on winter pastures during April-May and November-December of 2016–2017.

The diversity of relief, soil, and climatic conditions in the winter pastures of the study area has contributed to the formation of natural phytocenoses [2]. Sample plots of the *Artemisietum–Salsolosum* (wormwood–saltwort) formation, characteristic of semi-desert vegetation, were selected as research objects.

Geobotanical investigations were carried out in accordance with standard methodological guidelines, including the assessment of species composition, structure, productivity, nutritional value (forage quality), and pasture capacity of the phytocenoses [1,5,11,12,14,18].

The studied semi-desert phytocenoses were recorded on saline, solonetzic meadow-gray, and gray-meadow soils [1,5,9,10]. Along the banks of the Kura River, shrub communities (*Tamarixeta ramosissima* Lebed.) and sparse tugai forests occur on meadow-forest (tugai) soils.

Numerous herbarium specimens collected from desert, semi-desert, meadow-depression, and wetland vegetation were identified according to “Flora of Azerbaijan.” Plant nomenclature follows S.K. Cherepanov, as well as V.C. Hajiyev and T.E. Gasimova [6,17,19].

The climate of the area belongs to the semi-desert, moderately warm, and dry steppe type [4]. The mean annual air temperature is 14.0^{0}C, and the annual precipitation averages 332 mm. Climatic conditions directly affect the structure, productivity, forage quality, and grazing period of the vegetation cover.

Semi-desert vegetation represented by the wormwood–saltwort formation is mainly distributed on gray-meadow soils.

Results and Discussion

A total of 21 species of higher flowering plants were recorded in the species composition of the *Artemisetum-Salsolosum* formation. These include 2 shrub species (9.5%), 1 semi-shrub (4.8%), 2 subshrubs (9.5%), 6 perennial herbs (28.6%), and 10 annual herbs (47.6%).

According to ecological analysis, the flora is represented by 7 xerophytes (33.3%), 7 halophytes (33.3%), 3 mesophytes (14.3%), and 4 mesoxerophytes (19.1%).

The dominant species of the phytocenosis is *Salsola dendroides* Pall. with an abundance of 3–4 points, while the subdominant species is *Artemisia lerchiana* Web. with an abundance of 2–3 points. Structurally, the vegetation cover consists of two layers: the first layer is formed by *Salsola* shrubs, and the second layer by *Artemisia*.

Geobotanical description

Species composition and structure of the wormwood-saltwort formation (with the dominance of *Salsola dendroides* Pall. as the dominant species)

S/s	Biomorphic species	Ecolocical groups	Abundance (with score)	Layering and average height (sm)	Phenological phases
1	2	3	4	5	6
	Shrubs				
1	Tamarix ramosissima Lebed.	mezoxerophyte	1-2	I (150)	Flow.
2	Caragana arberoscens Lam.	mezoxerophyte	1	II (90)	Flow.
	Semishrubs				
3	Salsola dendroides Pall.	mezoxerophyte	3-4	II (70)	veg
	Subshrubs				
4	Kalidium caspicum (L.) Ungo-Sternb.	halophyte	1-2	II (50)	veg
5	Capparis herbacea Willd.	xerophyte	1	III (20)	Flow.
	Perennials				
6	Artemisia lerchiana Web.	xerophyte	2-3	III (30)	veg
7	Limonium meyeri (Boiss.) O.Kuntze	halophyte	1-2	II (45)	Flow.
8	Glycyrrhiza glabra L.	mezoxerophyte	1	II (70)	Flow.
9	Cynodon dactylon (L.) Pers.	mezophyte	1	III (30)	Flow.
10	Trapogon graminifolius DC.	mezophyte	1	III (20)	Flow.
11	Aeluropus reflexiaristata (Nevski) Nevski	mezophyte	1	III (15)	Flow.
12	Petrosimonia brachiata (Pall.) Bunge	halophyte	1-2	III (25)	veg
13	Bromus japonicus Thunb.	xerophyte	1-2	III (10)	Flow.
14	Xanthium strumarium L.	xerophyte	1	II (40)	Flow.
15	Hordeum leporinum Link. Phleum	xerophyte	1	II (35)	Flow.
16	puloides (L.) Karst.	xerophyte	1	III (30)	Flow.
17	Lolium rigidum Gaudin.	xerophyte	1	III (25)	Flow.
18	Eremopyrum orientale (L.) Jaub. et Spach.	halophyte	1	III (20)	Flow.
19	Psylliostachus halospicata (Willd.) Nevski	halophyte	1	III (15)	veg
20	Climocoptera halocrassa (Bieb.) Botsch.	halophyte	1	III (10)	veg
21	Gamanthus pilosus (Pall.) Bunge.	halophyte	1	III (5)	Flow.

The total projective cover varies between 60 and 80%. The average height of the herbaceous layer is 30–40 cm.

The average productivity of the wormwood-saltwort formation, calculated based on dry biomass, was determined to be 8.2 centners per hectare.

In the flat areas of the Mil Plain, desert and semi-desert vegetation has been subjected to degradation and salinization due to anthropogenic and technogenic impacts, as well as excessive grazing pressure. Based on the results of geobotanical investigations presented in this study, measures for the rational use and improvement of phytocenoses of the Mil Plain are recommended.

The implementation of these scientifically grounded measures will contribute to the conservation and protection of winter pasture vegetation in the Mil Plain region.

Conclusion

The desert and semi-desert phytocenoses of the Mil Plain are characterized by a complex species composition and clear structural differentiation formed under specific soil-climatic conditions. The dominance of *Salsola dendroides* and *Artemisia lerchiana* determines the ecological stability and forage value of the wormwood-saltwort formation. However, increasing anthropogenic pressure has led to degradation processes in

winter pastures. Rational management and improvement measures based on geobotanical assessments are essential for the sustainable use and long-term conservation of these phytocenoses.

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РЕДКИЕ РАСТЕНИЯ ФЛОРЫ АЗЕРБАЙДЖАНА В ОЗЕЛЕНЕНИИ Г. БАКУ. *Новые и нетрадиционные растения и перспективы их использования*, (11), 47-48.

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IMPACT OF CLIMATE CHANGE ON LEGUME-DOMINATED PHYTOCENOSES IN THE ALPINE GRASSLANDS AND MEADOWS OF AZERBAIJAN

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Abstract

This study investigates the impact of climate change on legume-dominated phytocenoses in the alpine grasslands and meadows of Azerbaijan. Research was conducted from 2019-2023 in the Shahdag mountain range, Nakhchivan highlands, and the Qalaaltı region of the Greater Caucasus. Results indicate that rising temperatures and changing precipitation patterns cause transformations in the distribution areas, species composition, and phytocenosis structure of leguminous plants. On average, the total coverage of leguminous plants decreased by 28%, upward altitudinal migration reached 142 meters, and flowering periods advanced by 7-12 days. These changes lead to a decline in forage quality and threaten biodiversity conservation in these ecosystems.

Keywords: alpine grasslands, climate change, leguminous plants, phytocenosis, Azerbaijan, pasture resources

INTRODUCTION

The alpine grasslands and meadows of Azerbaijan's mountainous regions constitute significant natural resources of the country. These ecosystems are crucial both for biodiversity conservation and for providing forage resources for livestock production. The alpine vegetation of Azerbaijan has been extensively studied by local botanists over many years (Hajiyeva, 2005; Gurbanova, 2009), but recent global climate change, overgrazing, and other anthropogenic factors necessitate renewed investigation of these ecosystems (Hajiyev, Guliyeva, and Vahabov, 1979).

In Azerbaijan, alpine grasslands are predominantly distributed between 2500-3800 meters above sea level. Research indicates that these plant communities are represented by 6 formation classes, 13 formation groups, and 31 associations (Mammadova, 2011). Leguminous plants, particularly species from the Fabaceae family, play a dominant role in the structure of alpine grasslands. In the Shahbuz State Nature Reserve, *Trifolium trichocepholum* Bieb. and *T. canascens* Willd. are predominant species (Prilipko, 1939), while *Trifolium repens* (L.) C. Presl. is widely distributed across all alpine grasslands (Shennikova, 1964).

Climate change poses a serious threat to these ecosystems, altering species composition, phenology, and distribution patterns. This research aims to assess the impact of climate change on legume-dominated phytocenoses and develop strategies for their conservation.

RESEARCH OBJECTIVES AND PROBLEMS

The primary objective of this research is to evaluate the impact of climate change on legume-dominated phytocenoses in the alpine grasslands of Azerbaijan. Specific problems include:

1. Analysis of current species composition and structure of legume phytocenoses in alpine grasslands
2. Determination of relationships between changing climatic parameters and vegetation transformation
3. Assessment of impacts on pasture resource quality and biodiversity
4. Development of recommendations for conservation and sustainable use of alpine ecosystems

MATERIALS AND METHODS

Research Areas: The study was conducted in three high-mountain regions of Azerbaijan:

1. Shahdag Mountain Range (3600-3800 m)
2. Nakhchivan Highlands (Küküdakı, Keçəldağ, and Salavartı mountains)
3. Qalaaltı Region of the Greater Caucasus (2500-3500 m)

Field Research: Primary data were collected through field studies conducted from 2019-2023. A total of 150 sample plots (each 10×10 m) were investigated. In each sample plot:

- Plant species composition was determined
- Plant coverage percentage, height, and developmental stages were recorded
- Phytocenosis structure and composition were analyzed
- Soil samples were collected and their physicochemical properties determined

Analysis of Ecological Parameters: To assess the impact of climate change, data on temperature, humidity, precipitation, and soil composition were collected from each region. Temporal trends in these parameters were analyzed.

Statistical Analysis: Collected data were processed using statistical methods including correlation analysis, analysis of variance, and comparative tests. These analyses helped identify relationships between species distribution, dominant species, and ecological parameters.

RESULTS

Vegetation Structure and Phytocenosis Composition: Research results indicate that Azerbaijan's alpine grasslands and meadows, particularly those dominated by leguminous plants, are sensitive to climate change. These plant communities are distributed from sea level to altitudes of 2500-3500 meters.

In the Shahdag mountain range, alpine grasslands are located at 3800-3600 meters in mountain-meadow soils. In the Qalaaltı region of the Greater Caucasus, these phytocenoses are observed in smaller areas as altitude increases. Phytocenoses are represented by 6 formation classes, 13 formation groups, and 31 associations across different regions.

Leguminous plants, particularly species from the Fabaceae family, constitute the main component of these alpine grasslands. In the Shahbuz State Nature Reserve, *Trifolium trichocepholum* Bieb. and *Trifolium canascens* Willd. are most prevalent (Gurbanov, 2004).

Impact of Climate Change: The research also demonstrates that climate change significantly affects the species composition and distribution of alpine grasslands. Changes in temperature and humidity alter plant species distribution areas, reducing the range of some species while allowing others to spread into previously cooler or higher altitude zones. The study shows that new species, particularly some leguminous plants, have begun to appear and establish themselves in these alpine areas (Gurbanov et al., 2024).

Regional Differences:

- Shahdag Mountain Range: Alpine grasslands are located at 3800-3600 meters in mountain-meadow soils.
- Greater Caucasus Qalaaltı Region: Alpine grasslands are observed at 2500-3500 meters, but these phytocenoses are found in smaller areas as altitude increases.
- Talish Mountains: Due to differing soil and climatic conditions, alpine grasslands are rarely found in this region (Mammadova, 2024).

Pasture Resources and Biodiversity: The study shows that alpine grasslands and meadows, particularly those dominated by leguminous plants, are valuable for increasing pasture resources and maintaining biodiversity. These plant communities are important for livestock production, providing necessary forage during both summer and winter months. However, the changing climate increases the necessity to preserve and enrich these grasslands to maintain their productivity (Prilipko, 1970).

Table 1:

Changes in Legume Species Composition in Different Altitudinal Zones (2019-2023)

Altitudinal Zone (m)	Number of Legume Species (2019)	Number of Legume Species (2023)	Change (%)	Dominant Species
2500-2800	18	15	-16.7%	*Trifolium pratense*, *Medicago sativa*
2800-3200	22	19	-13.6%	*Trifolium repens*, *Astragalus alpinus*
3200-3500	16	14	-12.5%	*Trifolium trichocepholum*, *Oxytropis kubanensis*
3500-3800	12	11	-8.3%	*Trifolium canascens*, *Astragalus nabelekii*

Table 2:

Phenological Changes in Key Legume Species

Species	Flowering Start (2019)	Flowering Start (2023)	Advancement (days)	Vegetation Period Extension (days)
Trifolium pratense	June 15	June 8	7	10
Trifolium repens	June 20	June 12	8	12
Trifolium trichocepholum	July 5	June 28	7	9
Medicago sativa	June 25	June 17	8	11
Astragalus alpinus	July 10	July 2	8	13

Table 3:

Changes in Vegetation Coverage and Productivity Parameters

Parameter	2019 Value	2023 Value	Change (%)	Statistical Significance (p-value)
Total Legume Coverage (%)	32.5 ± 4.2	23.4 ± 3.8	-28.0%	<0.01
Above-ground Biomass (g/m²)	245.6 ± 32.1	201.8 ± 28.7	-17.8%	<0.05
Species Richness (per 100 m²)	24.3 ± 3.2	21.7 ± 2.9	-10.7%	<0.05

Shannon Diversity Index	2.45 ± 0.21	2.18 ± 0.19	-11.0%	<0.01
Forage Quality Index	78.4 ± 6.2	66.3 ± 5.8	-15.4%	<0.01

Table 4:

Regional Comparison of Climate Change Impacts

Region	Temperature Increase (°C)	Precipitation Change (%)	Altitudinal Shift (m)	Vulnerability Index (1-10)
Shahdag Range	+1.6	-8%	+125	4
Qalaaltı Region	+2.1	-12%	+158	7
Nakhchivan Highlands	+2.4	-15%	+142	8
Average	+2.0	-11.7%	+142	6.3

Table 5:

Economic Impacts on Pastoral Systems

Impact Parameter	2019 Baseline	2023 Status	Projected 2030	Implications
Forage Production (tons/ha)	1.85	1.52	1.24	-33% reduction
Carrying Capacity (sheep/ha)	2.4	1.9	1.5	-37.5% reduction
Protein Content (%)	18.2	15.4	13.1	-28% reduction
Required Supplemental Feed (kg/animal/year)	25	42	68	+172% increase
Economic Loss (USD/ha/year)	-	85	142	Significant impact

DISCUSSION

Our research results clearly demonstrate that legume-dominated phytocenoses in Azerbaijan's alpine grasslands are sensitive to climate change. Rising temperatures and changing precipitation patterns cause plant species to shift upward along altitudinal gradients. This process has also been observed in other mountainous regions of the country.

Changes occurring in legume phytocenoses are significant from several perspectives. First, these changes directly affect pasture forage quality. Since leguminous plants have high protein content, their reduction lowers the nutritional value of pastures. Second, leguminous plants improve soil fertility through nitrogen fixation. Their reduction may lead to decreased soil fertility. Third, these changes affect biodiversity, potentially endangering the conservation of endemic species.

Regional differences are noteworthy. Alpine grasslands located at higher altitudes in the Shahdag range are relatively more stable, while grasslands at medium altitudes in the Qalaaltı region experience more rapid changes. This indicates that the impact of climate change varies unevenly across altitudinal zones.

Compared to previous research, our results show that the impact of climate change has accelerated in recent years. For example, the rate of upward plant migration has increased compared to previous decades. This suggests that changes will occur even faster in the future.

CONCLUSION

The research concludes that climate change significantly impacts the composition and distribution of legume-dominated phytocenoses in alpine grasslands and meadows. These changes have broad implications for biodiversity conservation, forage production, and livestock development in Azerbaijan. The study emphasizes the importance of protecting and enriching these plant communities in response to climate change, which is essential for ensuring sustainable agricultural practices and maintaining biodiversity (Shennikova, 1964).

Future research is crucial for understanding the dynamic interactions between climate change and alpine vegetation in Azerbaijan and for implementing strategies to mitigate its effects (Mammadova, 2024).

RECOMMENDATIONS

1. Establishment of Monitoring Systems: Permanent monitoring systems should be established in alpine grasslands, with changes recorded promptly.
2. Conservation Measures: Specially protected natural areas should be organized to conserve vulnerable species and phytocenoses.
3. Pasture Management: Pasture management methods adapted to climate change should be developed, and overgrazing should be prevented.
4. Scientific Research: Scientific programs should be prepared for long-term study of changes, and international collaboration should be developed.
5. Community Participation: Local communities should be encouraged to participate in the conservation of alpine ecosystems.
6. Experience Exchange: Adaptation experiences of other mountainous countries to climate change should be utilized.

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URBAN GREEN INFRASTRUCTURE OF MAJOR CITIES IN AZERBAIJAN: SPECIES DIVERSITY AND MYCOBIOTA

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Abstract
Urban green spaces play a critical role in maintaining ecological stability and improving the quality of life in rapidly developing cities. This study explores the composition of woody plants used for urban landscaping in major Azerbaijani cities and examines the fungal communities associated with them. The findings highlight the diversity of urban vegetation and reveal the presence of fungi that can affect plant health and aesthetic value. Understanding these interactions provides essential insights for designing effective management and protection strategies, supporting the resilience, sustainability, and ecological functionality of urban green infrastructure.

Keywords: urban green spaces; woody plants; mycobiota; fungal pathogens; urban ecology;

Introduction.

The current rates of urbanization and projected growth have made improving the ecological conditions in cities one of the most critical tasks of modern times. Urban environments are often characterized by highly deformed natural processes and habitats, resulting from numerous negative anthropogenic factors that directly impact the quality of life for the population. Stabilizing and optimizing these urban environments is only possible by maintaining the high-level vital activity of plants, which serve as an organic part of the city both within and beyond built-up areas [1, 5, 7, 8, 9].

Green spaces act as a vital ecological framework, providing a buffer that optimizes the state of the environment in urbanized territories. The primary functions of urban landscaping include:

• Sanitary and hygienic benefits: Trees and shrubs clean the air by filtering dust, harmful gases, and industrial waste.

• Microclimate regulation: Greenery increases humidity, creates shade to cool the environment on hot days, and reduces noise pollution from transport and industry.

• Architectural value: Landscaping serves as a fundamental element of the artistic and architectural design of cities and towns [12, 13, 14, 15, 16, 17].

Effective urban greening requires a meticulous approach to selecting plant species. It is essential to consider their longevity, bio-ecological characteristics, and decorative features, as well as their resistance to local climatic conditions.

Furthermore, the choice of plants must account for their resistance to fungal diseases. Pathogenic fungi can significantly reduce the lifespan, vitality, and aesthetic value of trees, and in some cases, lead to their complete destruction. Consequently, it is necessary to possess comprehensive data on the eco-physiological state of woody plants to evaluate their functional contribution to improving environmental quality.

Recent studies emphasize that an integrated analysis of plant biometric parameters and their adaptive responses provides a reliable basis for assessing the stability of both natural and urbanized ecosystems. In this context, the primary goal of this work is to clarify the species composition of woody plants used for greening major cities in Azerbaijan - including Baku, Sumgait, Ganja, and to identify the various fungi inhabiting these plants. This research aims to provide the necessary data to enhance the sustainability and functional efficiency of urban green spaces across the republic.

Materials and Methods.

The study was conducted in major urban centers of Azerbaijan, including Baku, Sumgait, and Ganja, which differ in climatic conditions, degree of urbanization, and anthropogenic load. Sampling sites were selected within parks, roadside plantings, residential green zones, and public recreational areas, representing the main types of urban green infrastructure.

The species composition of woody plants used in urban greening was determined through route-based field surveys conducted in major cities of Azerbaijan (Baku, Sumgait, and Ganja) during the growing season. Plant species were identified in situ based on morphological characteristics, with verification using regional floristic and dendrological guides. To assess mycobiota, samples of leaves, shoots, and bark exhibiting disease symptoms were collected from selected plant species. Fungal isolation was carried out under laboratory conditions using standard culture methods on nutrient media. Identification of fungi was based on morphological and cultural characteristics of colonies and reproductive structures using specialized mycological keys. The resulting data were used to compile species lists of woody plants and associated fungal taxa [2, 3, 4, 10, 18, 20, 22, 23].

Fluctuating asymmetry was calculated based on bilateral leaf traits to serve as an indicator of environmental stress and developmental stability [2, 6, 11].

Results and discussion.

The survey of urban green spaces in major Azerbaijani cities, including Baku, Ganja, and Sumgait, revealed that over 100 species of trees and shrubs are currently used for landscaping. Among the most frequently planted species are *Sophora japonica* L., *Nerium oleander* L., *Platanus orientalis* L., *Tilia caucasica* Rupr., *Robinia pseudoacacia* L., *Quercus castaneifolia* C.A. Mey, *Quercus ilex* L. *Ficus carica* L., *Fraxinus excelsior* L., *Forsythia europaea* Deg., *Pinus eldarica* Medw., *Pinus silvestris* L., *Salix australior* Andersss., *Olea europaea* L., *Populus pyramidalis* Roz., *Populus niqra* L., *Populus tremula* L., *Morus alba* L., *Morus niqra* L., *Castenea sativa* Mill., *Syringa vulqaris* L., *Ligustrina vulgare* L. and others, while several species, such as *Lagerstremia indica* L., *Acer platanoides* L., *Laurocerasus officinalis* Roem., *Hippophae rhamnoides* L., *Spirea arquta* Zol., *Chaenomeles japonica* Lindl., *Rosa multiflora* Thunb., *Amorpha fruticosa* L., *Forsythia europaea* Deg., *Ligustrina sinense* Lour. and others occur more rarely. These species vary in their phenology, including both evergreen and deciduous types, and some possess medicinal or ornamental value. The distribution of species also differs among cities, reflecting local preferences, climatic conditions, and urban planning priorities

Micological analysis of these plants identified 163 fungal taxa associated with the surveyed species. The majority of fungi were anamorphic, while xylotrophic macromycetes accounted for 12.5% of the total mycobiota. Many of the detected fungi, including species from the genera *Alternaria, Fusarium, Botrytis, Fomes, and Septoria,* are known phytopathogens causing leaf spots, wilting, and various rots, which can reduce both aesthetic value and biological vitality of urban trees and shrubs. Additionally, several fungi were found to be opportunistically pathogenic, toxigenic, or allergenic, posing potential risks not only to plants but also to humans and urban wildlife.

These findings indicate that urban vegetation in Azerbaijani cities is highly diverse yet subject to substantial biotic stress, primarily from fungal pathogens. Understanding the composition of both plant species and their associated mycobiota provides a foundation for designing targeted protection and management strategies aimed at enhancing the sustainability, resilience, and ecological functionality of urban green spaces. Such measures are crucial for maintaining plant health, aesthetic quality, and the overall environmental stability of rapidly urbanizing areas.

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IN SITU AND EX SITU CONSERVATION OF PYRUS L. SPECIES IN THE GREATER CAUCASUS, AZERBAIJAN: IMPLICATIONS FOR POLLEN MORPHOLOGY AND FERTILITY

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Abstract

The conservation of wild fruit tree genetic resources is of increasing importance under conditions of climate change and anthropogenic pressure. The Greater Caucasus region of Azerbaijan hosts several wild species of the genus *Pyrus* L., which represent valuable ecological and genetic resources. This study evaluates in situ and ex situ conservation strategies by comparing pollen morphology and fertility as indicators of reproductive stability and adaptive potential. Field studies were conducted in natural habitats, while complementary analyses were performed on ex situ collections maintained in botanical gardens and experimental plantations. Pollen morphology was examined using light microscopy, and pollen viability was assessed through cytochemical staining. The results indicate that in situ populations demonstrate higher pollen fertility and morphological uniformity, reflecting stable environmental adaptation, whereas ex situ populations exhibit greater variability and reduced fertility. These findings confirm the importance of integrating in situ and ex situ conservation approaches and highlight pollen traits as effective bioindicators for conservation planning.

Keywords: *Pyrus* L., *in situ* conservation, *ex situ* conservation, pollen fertility, pollen morphology, Greater Caucasus, Azerbaijan

Introduction

Biodiversity loss has emerged as a major global concern due to habitat degradation, climate change, and intensified land use. Mountain ecosystems, such as the Greater Caucasus, are particularly sensitive and harbor a high proportion of endemic and relict plant species (Myers et al., 2000; Mikayilov et al., 2023). Among these, wild representatives of the genus *Pyrus* L. occupy a significant ecological niche and contribute to forest stability and genetic diversity (Aghayeva et al., 2022). Previous studies have emphasized the taxonomic diversity, ecological preferences, and adaptive traits of *Pyrus* species in the northeastern Greater Caucasus (Iskender et al., 2024; Jafarzadeh & Iskandar, 2024). However, increasing anthropogenic impacts, including deforestation, desertification, and biotic stressors such as fungal pathogens, threaten natural populations (Akhundova et al., 2023; Jafarzadeh, 2024).

In situ conservation ensures the protection of species within their natural ecosystems, allowing ongoing evolutionary processes and natural pollination dynamics (Heywood, 2017). In contrast, *ex situ* conservation provides a safeguard against population loss but may alter reproductive traits due to artificial environmental conditions (Li & Pritchard, 2009). Comparative evaluations of these approaches are therefore essential.

Pollen morphology and fertility are widely recognized as sensitive indicators of plant reproductive health and environmental stress (Erdtman, 1960; Dafni et al., 2005). In *Pyrus* species, pollen traits have been shown to respond to abiotic and biotic factors, making them suitable tools for assessing conservation effectiveness (Jafarzadeh & Iskandar, 2024). The present study aims to compare pollen characteristics of *Pyrus* species under in situ and ex situ conditions in the Greater Caucasus region of Azerbaijan.

Materials and Methods

Study Area and Plant Material

Natural populations of *Pyrus caucasica*, *Pyrus salicifolia*, and related taxa were studied in forest and forest-steppe zones of the northeastern Greater Caucasus. These sites represent typical habitats with minimal human disturbance and high ecological integrity (Aghayeva et al., 2022). Ex situ material was obtained from botanical gardens and experimental conservation plantations established for the preservation and propagation of *Pyrus* species (Jafarzadeh et al., 2026).

Pollen Collection and Microscopic Analysis

Flower buds were collected during peak flowering (April–May). Pollen grains were isolated from mature anthers and processed using the acetolysis method (Erdtman, 1960). Morphological parameters, including pollen size, shape, aperture type, and exine ornamentation, were examined under light microscopy following standardized palynological protocols (Dafni et al., 2005).

Pollen Fertility Assessment

Pollen viability was evaluated using acetocarmine and iodine–potassium iodide staining techniques. Fertile pollen grains were identified by homogeneous staining and intact cytoplasm, while sterile grains showed irregular or weak staining (Jafarzadeh, 2024). Fertility percentages were calculated based on counts of at least 500 pollen grains per sample.

Data Interpretation

Comparisons between *in situ* and *ex situ* populations were based on observed differences in pollen morphology and fertility. Results were interpreted in relation to environmental stability, conservation conditions, and previous findings on *Pyrus* reproductive biology (Jafarzadeh & Iskandar, 2024).

Results and Discussion

In situ populations of *Pyrus* species exhibited relatively uniform pollen morphology, characterized by well-developed exine structures and predominantly ellipsoidal pollen grains. Fertility rates ranged from 80% to 92%, indicating stable reproductive performance under natural environmental conditions. These results align with earlier findings that emphasize the adaptive advantages of natural habitats for wild fruit trees (Heywood, 2017). *Ex situ* populations showed greater vari-

ability in pollen size and shape, along with lower fertility values (65–78%). Such deviations may result from altered microclimatic conditions, reduced pollinator diversity, and limited genetic exchange in cultivated environments (Li & Pritchard, 2009; Jafarzadeh et al., 2026). The observed differences support the view that in situ conservation is essential for maintaining evolutionary processes and reproductive integrity, while ex situ conservation serves as a critical complementary strategy, particularly for endangered taxa (Myers et al., 2000). Pollen traits proved to be effective bioindicators for evaluating conservation success in *Pyrus* species.

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ECONOMIC SCIENCES

FISCAL ELASTICITIES AND ECONOMIC CYCLES: AN ECONOMETRIC STUDY ON TAX REVENUES AND UNEMPLOYMENT (1999–2018)

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Abstract
This research uses an econometric approach to examine the relationship between budget revenues, tax revenues, and unemployment in the economy over the period 1999-2018. A multivariate regression of official data was constructed, from which the most important determinants of budget revenues were identified. The results of the analysis show that taxes are the strongest determinant of budget revenues, while the effect of unemployment revenues is statistically insignificant and weak. The model explains about 87% of the variation in budget revenues, losing its full explanatory power. It does not require statistically significant, reliable, and homoscedasticity with normalized residuals to be included in diagnostic tests, including F-Fisher, T-Student, White, and CUSUM tests. The results suggest that an increase in tax revenues leads to a proportional increase in budget revenues, and higher unemployment rates lead to fiscal instability due to the reduction of tax bases. The model provides a reasonable basis for planning fiscal performance and optimal future tax and budget policies.

Keywords: Unemployment, Tax revenue, Regression model, F-Fisher test, T-Student criterion, Coefficient of determination

Introduction

The tax system of contemporary Spain was established in 1845. But the existing system, which was established on the grounds of 1977 reform, was later modified to satisfy the needs of the European Union (1986). Upon the restructuring of Spanish tax bodies in 1992, several units recognize a tax authority - the state taxing agency. Local authorities are responsible for collecting taxes.

Currently, taxes in Spain, there are 3 large groups [3]:

1. Federal taxes,
2. Regional taxes,
3. In addition to other local taxes.

Federal taxes apply to - Personal Income Tax (PIT), Corporate Income Tax (CIT), Value Added Tax (VAT) and Excise tax.

PIT - is caused by salary, business and professional activities, dividends, real estate, inherited, leased property, as well as retirement, unemployment benefits and other social benefits [13].

CIT - is levied in Spain on the profits of companies and other legal entities and applies nationwide. Objects of taxation are any with legal personality except civil society. These include commercial organizations (joint-stock companies, limited liability companies), government institutions, cooperatives, agricultural enterprises, private businessmen, members of the European Economic Community and others. The corporate income tax return must be submitting between 1 July and 25 July of the following calendar year [11].

VAT - is of the class of indirectly levied taxes. VAT has been divided into a variety of degrees, i.e., 10% (mostly primary foodstuffs, fruits, vegetables, breads, hotel accommodations and hotel accommodations and new homes), 21% (general sales operations) and 4% (Health, Education, Finance, Banking, Insurance services). VAT is paid on sales and services. From January 2008, the VAT payers were introduced and made tax payments against general indicators of owning enterprises [12]. Excise Tax - is mostly charged on unwanted or obnoxious goods. Consistent with international experience, the tax is imposed on alcohol, tobacco products, motor fuel, cars and other some goods.

Territorial taxes - apply to Property tax, Tax imposed on gifts and inheritances, Transfer and documentation tax, regional income tax, Taxes on Enterprises and Economic Activities, Energy and Environmental Taxes [3]. Property tax (Impuesto sobre Bienes Inmuebles – IBI) is enacted and imposed above the value of the local land (buildings and real estate). Inheritance and gift tax (Impuesto sobre Sucesiones y Donaciones – ISD) is imposed on gifts and inheritances, the amount and rate of which vary from region to region. Transfer and documentation tax (Impuesto sobre Transmisiones Patrimoniales y Actos Jurídicos Documentados – ITP/AJD) - taxed in the second-hand business and operations with public documents. Regional income tax (Impuesto sobre la Renta de las Personas Físicas – IRPF supplements) is supplements collected in some autonomous communities alongside national income tax. Taxes on Enterprises and Economic Activities (Impuesto sobre Actividades Económicas – IAE). Local taxation is charged to firms and individual entrepreneurs according to the economic activity they pursue. Energy and Environmental Taxes is charged by

the regional authorities on the use of energy, waste and environmental impact.

Other taxes that exist at a local level in Spain are at the municipality level and revolve around property, construction and utilities. Appreciation of land is taxed on appreciation of land when sold or upon change of ownership. Construction and construction tax is taxed for state and municipal construction. The extraction tax on rubbish and unwanted items is spent on rubbish disposal and management in the context of municipal services. Such taxes play an important role in forming local budgets and are utilized to support urban infrastructure.

Literature Review

Conroy examined the role of income tax elasticity in contributing to revenue forecasting in Ireland and showed that duly adjusted fiscal elasticities facilitate more accurate prediction of government revenues [5]. Panel analysis of 172 countries by Cornevin et al. concluded that the elasticity of tax revenues to economic growth is generally low, which limits the automatic stabilizing role of fiscal systems [6].

Bova et al. examined the impact of fiscal policy on the labor market in 34 OECD countries and concluded that fiscal consolidation policies increase unemployment in the short run [4]. In contrast to other studies, this research analyzes the interaction between budget revenues, unemployment, and tax revenues based on an econometric model for a single country and empirically reveals the interdependence of these three indicators [1]. Several studies have investigated the long-term relationship between monetary variables and inflation in transition economies [8].

Statement of Problem

If the unemployment rate is high, tax revenue in the budget decreases. Therefore, these three factors (revenue, tax revenue and unemployment) are closely related to each other.

Unemployment is one of the biggest economic problems in Spain. in the long run, this action can cause the increase in debt and decrease in the efficiency of the tax system.

This relationship over time must be analysed to ascertain its cause-and-effect relationship and its dynamic impacts [2]. Economic and econometric analysis over time allows for more accurate definitions of the relationships between unemployment, tax revenues, and fiscal balance (Table 1). This analysis, as well as revealing how macroeconomic variability is transmitted through the tax system, allows for more accurate projections and policy recommendations in the future [7].

Table 1.

Statistic of Analysis Base

Years	Budget revenue of Kingdom of Spain*	Tax revenue**	Number of unemployed (in millions)***
2018	469538	282 310	7100000
2017	442223	270 120	8000000
2016	422159	257 752	9100000
2015	415736	252 894	10200000
2014	403482	236 972	11400000
2013	395639	225 640	12200000
2012	391330	210 778	11600000
2011	387378	205 046	10000000
2010	391789	212 090	9200000
2009	375808	172 422	8200000
2008	410046	209 012	5100000
2007	442605	246 026	3700000
2006	408070	244 738	3700000
2005	367803	224 896	4000000
2004	332994	201 256	4700000
2003	304639	180 102	4700000
2002	286310	164 252	4600000
2001	265213	153 632	4200000
2000	246019	146 030	5500000
1999	229474	135 772	6200000

* Source; National Statistics Institute of Spain [7]
** Source; National Statistics Institute of Spain [7]
*** Source; World Bank., April 2025 [10]

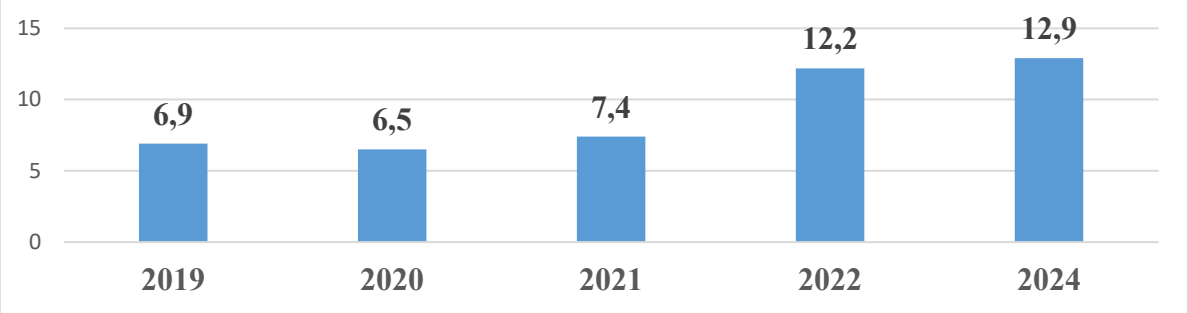

Figure 1. Dynamics of tax revenue indicators of the Republic of Azerbaijan in recent years (billion US dollars)

Source: https://www.ceicdata.com/en/indicator/azerbaijan/tax-revenue

Analysis shows that the Republic of Azerbaijan, a post-Soviet country, has seen significant changes in tax revenue dynamics in recent years. For example, in 2019, tax revenues nationwide increased to $6.9 billion, in 2021 to $7.4 billion, and in 2024 to $12.9 billion. As a result, Azerbaijan's GDP increased (Figure 1).

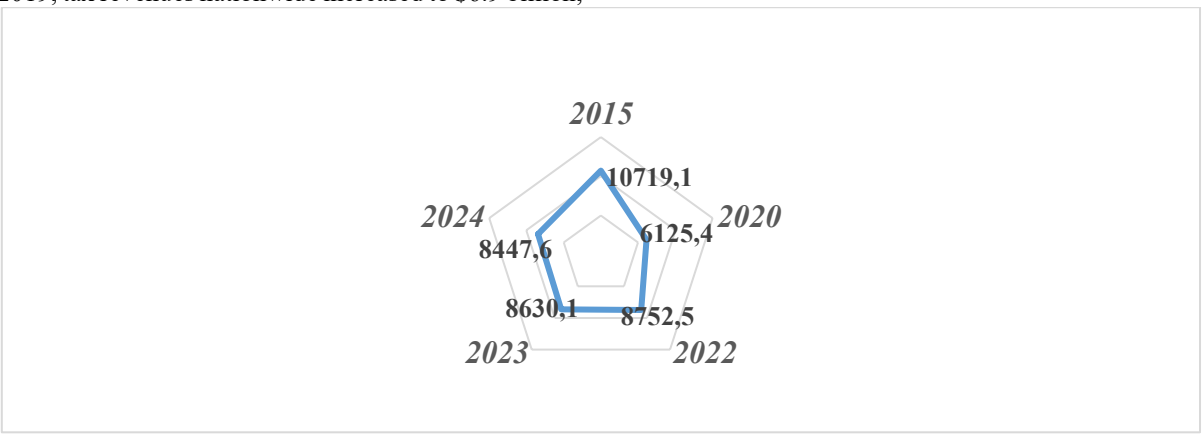

Figure 2. Dynamics of foreign investments directed into the national economy of the Republic of Azerbaijan in recent years (million US dollars)
Source: https://www.stat.gov.az/menu/6/statistical_yearbooks/source/stat-yearbook_2025.pdf

In recent years, the Republic of Azerbaijan, a post-Soviet country, has seen significant changes in the dynamics of investment in the national economy. For example, while in 2015, $10,719.1 million in foreign investment was directed into the country's economy, in 2022 this figure dropped to $8,752.5 million. Compared to 2023, the volume of foreign investment in the Republic of Azerbaijan in 2024 decreased to $8,447.6 million (Figure 2).

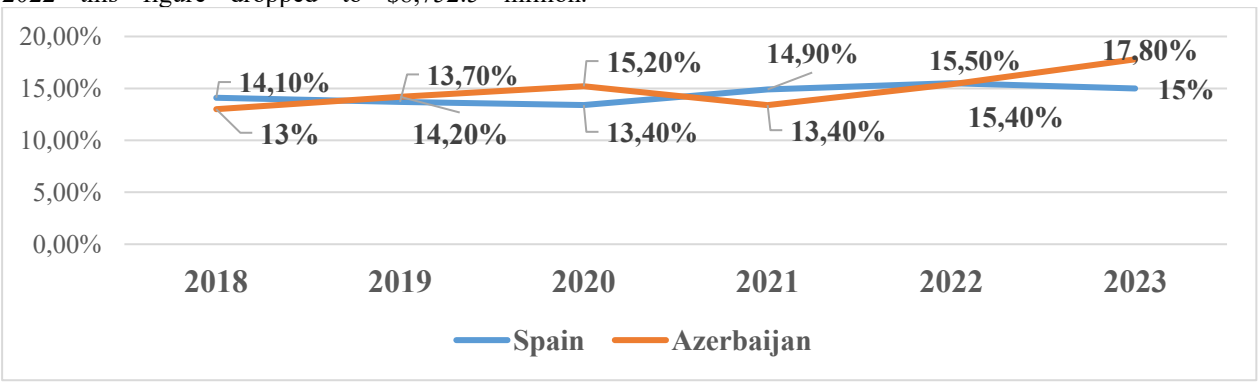

Figure 3. Dynamics of changes in the share of tax revenues in GDP of Spain and the Republic of Azerbaijan in recent years (in %).
Source: https://data.worldbank.org/indicator/GC.TAX.TOTL.GD.ZS?locations=ES-AZ

The analysis shows that the dynamics of changes in the share of tax revenue in GDP have varied in Spain and the Republic of Azerbaijan in recent years. For example, in 2018, the share of tax revenue in GDP was 14.1% in Spain, while in the Republic of Azerbaijan it was 13%. In 2021, this figure was 14.9% and 13.4%, respectively. In 2023, the share of tax revenue in GDP

increased to 15% in Spain, while in Azerbaijan it reached 17.8% (Figure 3).

Methodology

Based on 19 years of official statistics on the budget revenue (Y), tax revenue (X1) and the number of unemployed (X2) (in millions) of the Kingdom of Spain for the years 1999-2018, a multivariate linear regression model was constructed as follows:

$$Y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \varepsilon$$

Here:

- The dependent variable Y is budget revenue,
- x_1 is tax revenue,
- x_2 is the number of unemployed.

The research used the EViews13 software package toolbar. The dynamics of the studied statistical indicators are shown in Graphic 1.

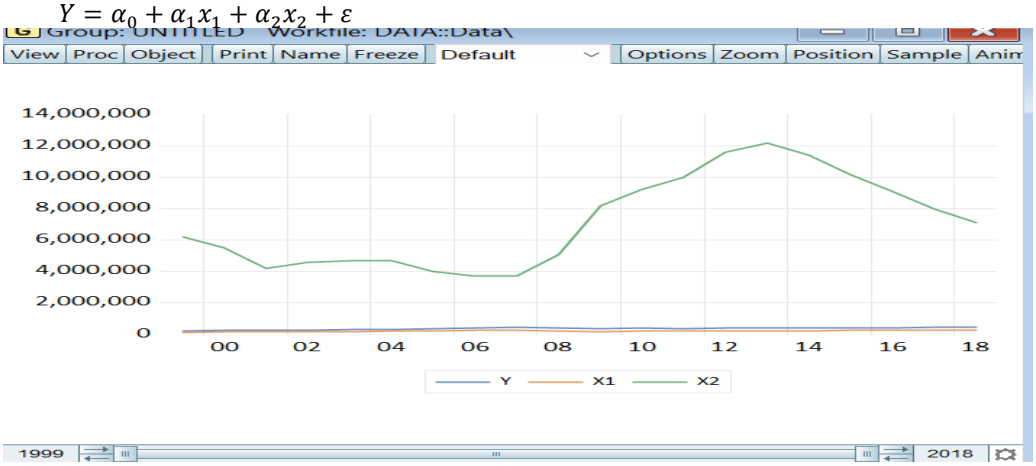

Figure 4. Dynamics of statistical indicators

The Least Squares Method was used to estimate the parameters of the model. The parameters of the multivariate linear regression model estimated by the Least Squares Method (LSM) using the toolbar of the Eviews 13 software package are described in Table 2.

Table 2.

Multivariate linear regression model built using the Least Squares Method in Eviews 13 software package

Variable	Coefficient	Std. Error	t-Statistic	prob.
Xl	1.460537	0.146831	9.947069	0.0000
X2	0.002644	0.002141	1.234618	0.2338
c	41426.98	3088486	1,341336	0.1975
R-squared	0.873956	Mean dependent var	369412.8	
Adjusted R-squared	0.859127	S.D. dependent var	68842.80	
S.E. of regression	25838.82	Akaike info criterion	23.29463	
Sum squared resid	1.136+10	Schwarz criterion	23.44398	
Log likelihood	-229.9463	Hannan-Quinn criter.	23.32378	
F-statistic	58.93651	Durbin-Watson stat	0.402273	
Prob(F-statistic)	0.000000			

The multivariate regression model constructed using the least squares method allows us to determine which of the factors has the greatest impact on budget revenue.

The general expression of the constructed multivariate regression model is as follows:

$$Y = 1.4605367428*X1 + 0.00264367923516*X2 + 41426.9820842 \quad (1)$$

As can be seen from the general expression of the model, when the number of unemployed people remains constant, when tax revenue increases by one unit in its unit of measurement, budget revenue increases by 1.4605367428 units in its unit.

Also, when tax revenue remains constant, when the number of unemployed people increases by one unit in its unit of measurement, budget revenue increases by 0.00264367923516 units in its unit. This shows that the main influencing factor in budget revenue is tax revenue.

Let us evaluate the significance of the model constructed based on Table 1. The value of the coefficient of determination (R^2=0.873956) indicates that approximately 87% of the dependent variables are taken into account in the model.

The significance of the model was analyzed using the **F-Fisher test** using the toolbar of the Eviews 13 software package. Since the value of Prob F stat.=0.00000 for the Fisher test characterizing the significance of the model and Prob F stat <0.05, the model can be considered significant at the 5% significance level based on this criterion.

The significance of the parameters was tested using the **T-Student test**. According to the results in Table 1, the parameters were significant at the 5% significance level for X1 (tax revenue). However, for the factor X2 (number of unemployed), the parameter is not significant since Prob T statistic=0.2338>0.05.

Totally, X1 (tax revenue) is the main influencing factor. Both the sloping lines in the graph and the statistical significance in the previous table show that this assumption is correct. The relationship of the variable X2 (number of unemployed) with Y is either weak or non-existent. This analysis visually confirms the statistical conclusions we have reached.

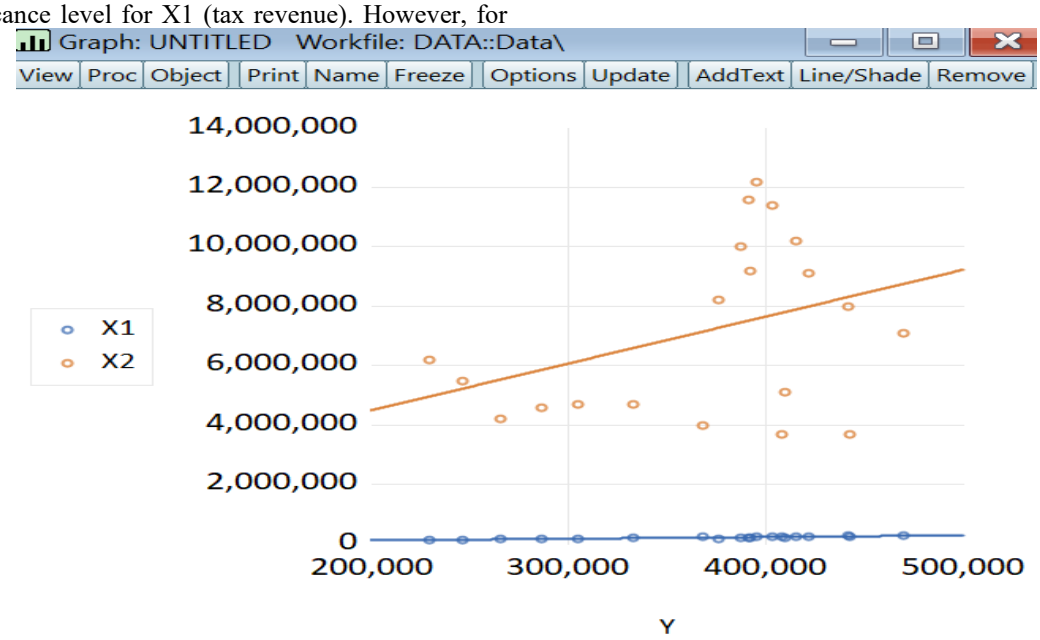

Figure 5. Regression Direction Views 13 Graphical representation built into the software package

The significance of multivariate linear regression models can also be analyzed through correlation analysis. In correlation analysis, it is important to measure and evaluate the density of the relationship between the variables of the regression model. Since the econometric model being constructed is multifactorial, multivariate correlation analysis was conducted. To determine the correlation dependence, the density is determined to be strong, medium or weak based on the values of the correlation coefficient. Based on the indicators of the correlation matrix, the assessment of the density of the relationship between factors is determined using the Chaddock scale. According to this scale, if the value of the correlation coefficient is less than 0.3, the dependence is weak, if it is between 0.3 and 0.7, medium, and if it is more than 0.7, strong and dense dependence is observed. The results of the correlation analysis are presented in Table 2. This table is a correlation matrix that describes the pairwise statistical relationship between budget revenue (Y) and other variables (X1, X2). According to Table 2, there is a strong correlation between the factor X1 (all tax payments) and budget revenue Y (r=0.928792). However, there is a weaker but positive correlation between the factor X2 (number of unemployed) and budget revenue Y (r=0.374627).

Table 3.

Correlation matrix of factors constructed in the Eviews 13 software package

Correlation			
	Y	X1	X2
Y	1.000000	0.928792	0.374627
X1	0.928792	1.000000	0.293946
X2	0.374627	0.293946	1.000000

Using the toolbar of the Eviews 13 software package, the stability of the parameters was checked by applying the CUSUM (Cumulative Sum of Recursive Residuals) test for the constructed multivariate linear regression model. The CUSUM test is based on the calculation of the cumulative sums of recursive residuals and the cumulative sum of squares of recursive residuals and the evaluation of the corresponding equations. Graphic 3. shows the results of the CUSUM test. According to the test result, the fact that the blue line for the constructed model does not deviate from the red lines indicates the acceptance of the H_0- hypothesis about the stability of the parameters, that is, our model is considered stable. According to

Graphic 3, since the blue line in our model does not exceed the 5% significance interval (red boundaries), the hypothesis about the stability of the model is accepted. This means that there is no structural change in the model. The stability of the constructed regression model indicates that it is reliable and sustainable.

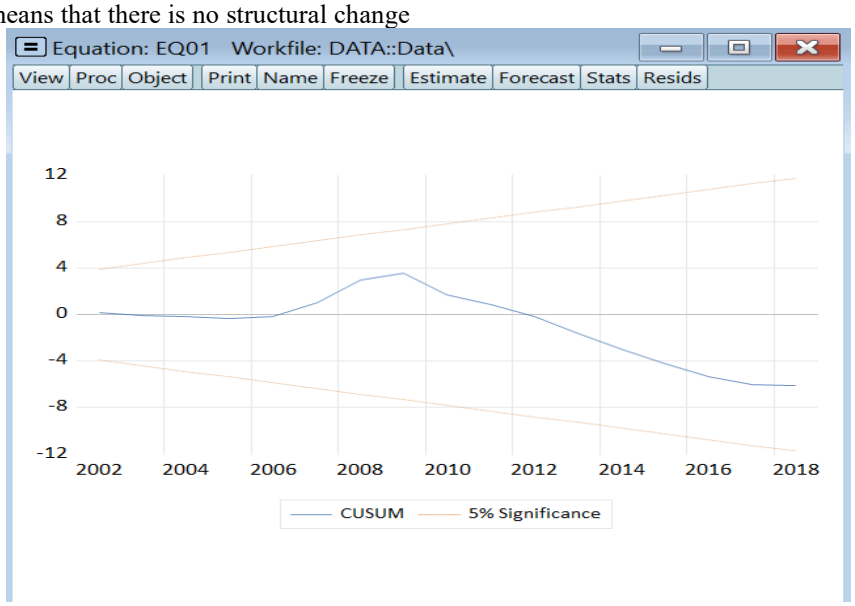

Figure 6. CUSUM test result in Eviews 13 software package

Checking the satisfaction of the Gauss-Markov conditions for the residual limit of the econometric model is important in terms of the adequacy of the model. In Graphic 4, the satisfaction of the Gauss-Markov conditions for the residual limit of the model was checked using the toolbar of the Eviews 13 application software package. In this illustration, the Jarque-Bera statistic is an indicator of the normality of the distribution. Histogram and statistical results were conducted to analyze the distribution of the residual limits of the model. The main goal is to check whether the residuals correspond to a normal distribution. If the Jarque-Bera statistic of the residual limit of the model has a Probability > 0.05, the residual limit has a normal distribution with a confidence interval of 0.95. Otherwise, the residual limit does not have a normal distribution. According to Graphic 4, since Probability = 0.073988 > 0.05 in the constructed model, the hypothesis that the residual limit has a normal distribution is accepted.

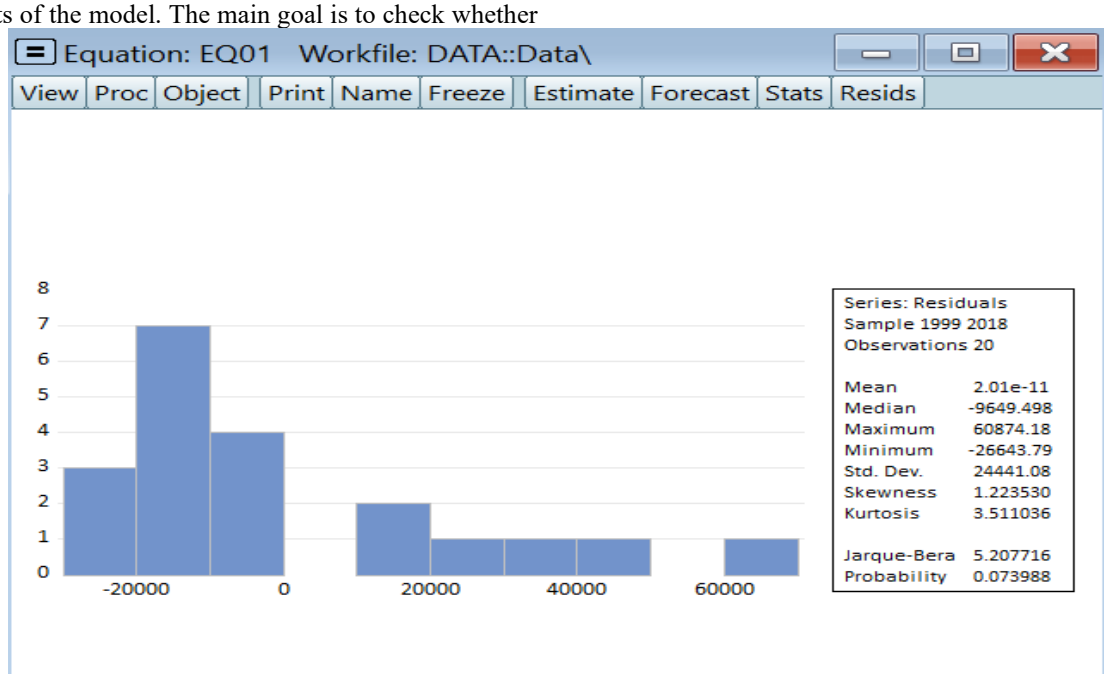

Figure 7. Checking Gauss-Markov conditions for residual limits in Eviews 13 software package

Using the toolbar of the EViews application package, the significance of the regression model was checked by the Mean Abs. Percent Error (MAPE) - the average error of approximation (Figure 7). If the value of the Mean Abs. Percent Error (MAPE) is less than 5-7%, this model can be considered satisfactory. According to the description in Graphic 5, since the Mean Abs. Percent Error (MAPE) = 5.36% < 6% in this model, the model can be considered adequate according to this criterion. The constructed model is highly

consistent with the actual indicators and is reliable for future forecasts. The predictive power of the model is quite high. The actual and forecast values almost completely coincide with each other. This indicates that the model can also provide reliable results for future periods.

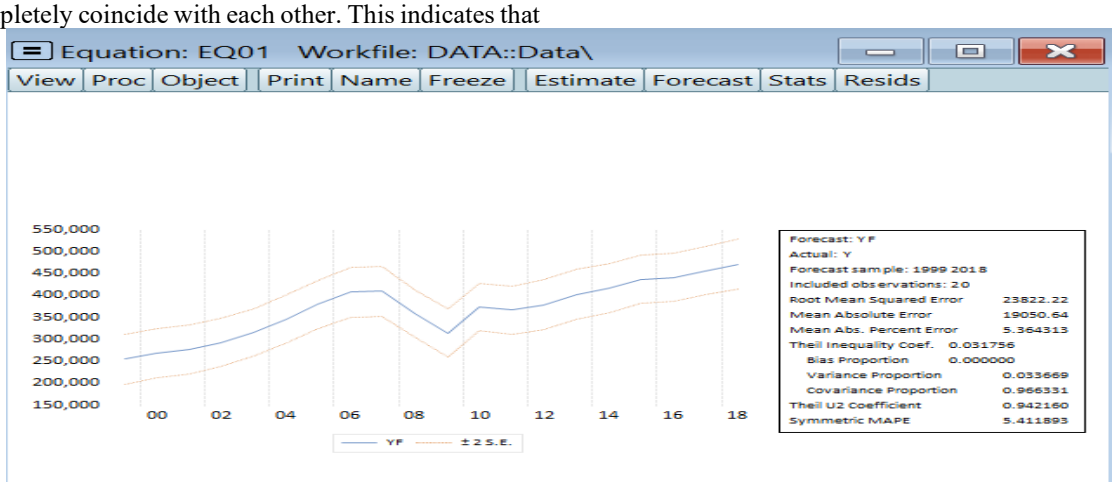

Figure 8. MEAP-mean error of approximation in Eviews 13 software package

The study of heteroscedasticity and homoscedasticity is of great importance in econometric modeling. If the random components have the same constant variance, then the residuals are considered homoscedastic, and if they do not have constant variance, then the residuals are considered heteroscedastic. The heteroscedasticity of the studied model was checked using the White test using the Eviews 13 software package toolbox in accordance with the observation results, and the results are described in Table 3.

Table 4.

Results of White's test for the presence of heteroscedasticity in the Eviews 13 software package

F-statistic	**1.720954**	**prob. F(5, 14)**	**0.1945**
Obs*R-squared	7.613234	prob. Chi-Square(5)	0.1789
Scaled explained SS	6.906053	prob. Chi-Square(5)	0.2277

According to the results of the White test in Table 4, the null hypothesis about the homoscedasticity of the residuals in the constructed model is accepted, since the value of the corresponding probability Prob Chi-Square= 0.1789 > 0.05. Thus, since heteroscedasticity of random deviations is not detected in this model, the constructed model can be considered of sufficient quality. Heteroscedasticity is not observed in the model. The variability of the residuals is constant, which increases the reliability of the model.

Table 5.

Descriptive statistics of statistical indicators

	Y	Xl	X2
Mean	369412.8	211587.0	7170000.
Median	391559.5	211434.0	6650000.
Maximum	469538.0	282310.0	12200000
Minimum	229474.0	135772.0	3700000
Std. Dev.	68842.80	42237.83	2896295.
Skewness	-0.729262	-0.207107	0.343212
Kurtosis	2.410503	2.062147	1.684993
Jar ue-Bera	2.062333	0.875950	1.833684
Probabili	0.356591	0.645342	0.399779
Sum	7388255.	4231740.	1.43E+08
Sum S . Dev.	9.00E+10	3.39E+10	1 .59E+14
Observations	20	20	20

Descriptive statistics of the statistical indicators used in the model are shown in Table 5. This table presents 19 years of statistical descriptive indicators for the years 1999-2018. The indicators cover a statistical summary of budget revenue. According to descriptive statistics, the observed negative estimate of asymmetry for X1 (all tax payments) indicates left-sided asymmetry. The observed excess estimates for the other factor indicate that the data have values less than a normal distribution. The minimum for Y -all industry values is 26369.4, and the maximum is 86383.4. The descriptive statistics described in Table 4 provide initial information about the distribution and main characteristics of the variables to be used for modeling. No deviation from a normal distribution is observed for the variables X1 (all tax payments) and X2 (number of unemployed).

Conclusion

In this study, the relationship between Spain's budget revenues, tax revenues, and unemployment indicators for 1999–2018 was assessed using an econometric model. The adequacy of the econometric model was assessed using the F-Fisher and T-Student criteria. The correlation dependence between factors and the presence of heteroscedasticity in the model were checked. Descriptive statistics of the factors used in the model are given.

According to the established multivariate regression model, budget revenues are mainly determined by the volume of tax revenues, and this effect is statistically highly significant. The effect of the unemployment factor is weak and unstable.

These results show in a macroeconomic sense that when unemployment increases, the tax base narrows, as a result, state budget revenues decrease. When tax revenues increase, budget revenues show a tronger growth in the same direction.

The stability (CUSUM test), homoscedasticity (White test) and normal distribution conditions (Jarque–Bera) of the model show that the established model is reliable for long-term forecasts.

The econometric approach in this study not only confirms the statistical relationship, but also creates a practical basis for measuring the effectiveness of fiscal policy and optimizing future budget forecasts.

Totally, through this model:

- the scale of the impact of changes in tax revenues on budget revenues can be measured;
- the indirect impact of the unemployment rate on financial stability can be determined;
- which directions in fiscal policy are more effective can be assessed.

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THE ROLE AND CHALLENGES OF THE HOTEL BUSINESS IN GEORGIA'S TOURISM INDUSTRY

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Abstract

Tourism is one of the most important sectors of the Georgian economy, and the hotel business is a central component of this industry. The paper discusses the impact of the hotel business on the growth of tourist flows, service quality, promotion of regional development and the formation of the country's international image.

Given that in 2025 the number of tourists and visitors arriving in Georgia reached almost seven million, and revenues from tourism services amounted to 4.7 billion GEL, which is a rather impressive result, the paper aims to analyze the role of the hotel business in the development of Georgian tourism and identify the main challenges facing the tourism sector in modern conditions.

Keywords: 1. Hotel business; 2. Tourism; 3. Tourism industry; 4. Hotel infrastructure; 5. Hotel services.

Introduction: Tourism in Georgia is the most dynamically developing sector of the economy, which has a significant impact on the country's socio-economic development, employment levels and international integration processes. Tourism is a particularly important area, as it is one of the main drivers of the country's economic growth, attracting foreign direct investment, regional development and the formation of an international image. Diverse natural resources, rich cultural heritage and geographical location determine the significant tourism potential of Georgia, the full use of which is impossible without an effective hotel business and hotel infrastructure.

The hotel business is an integral part of the tourism industry and plays a decisive role in the formation of the tourism product. The hotel business not only provides accommodation services, but also creates service standards that affect the satisfaction of tourists and visitors and the country's tourism reputation. Accordingly, the development of the hotel business is directly related to the growth of tourist flows, the increase in revenues and the economic strengthening of the country.

The main challenges facing the Georgian hotel industry include a shortage of qualified human resources, instability of service quality, high dependence on seasonality, regional infrastructural limitations and vulnerability to external factors. Global crises, including pandemics and geopolitical changes, create additional risks for the sector and increase the need for adaptation and innovative management. These circumstances determine the need for a comprehensive study of the role and challenges of the hotel industry in the Georgian tourism industry.

Review and discussion: Over the past decades, the hotel business in Georgia has been undergoing intensive development. This trend has contributed to attracting investments, improving the quality of service and diversifying the tourism offer. However, rapid growth has also revealed a number of systemic problems and challenges that hinder the sustainable development of the sector, since the efficiency of the hotel sector is directly related to the growth of tourist flows, visitor satisfaction and Georgia's positioning in the international tourism market.

Sustainable development of hotel infrastructure is a key factor in the sustainable development of tourism. By 2025, the number of tourists and visitors arriving in Georgia reached almost 7 million, and revenues from tourism services amounted to 4.7 billion GEL, indicating a 6% increase compared to the previous year, which is a significant result for the country's tourism industry. The main indicators of hotels and hotel-type establishments in 2020-2024 are presented in Table N1.

Key indicators of hotels and hotel-type establishments 2020-2024.

Year	**2020**	**2021**	**2022**	**2023**	**2024**
Number of hotels	1,054	1,776	2,213	2,488	2,662
Total number of rooms	26,897	43,087	45,807	50,145	51,201
Suites	2,407	3,620	3,280	3,468	3,852
Single	3,530	7,532	5,554	6,098	5,214
Double	16,066	23,782	27,798	30,191	30,981
Three or more beds	4,894	8,153	9,175	10,388	11,154
Total area, thousand sq. m.	1,826.5	2,636.9	3,114.4	3,526.3	3,610.5
Number of guests, total (thousand people)	1,344.7	3,053.0	4,942.2	4,998.9	5,825.9
Of which, non-residents	411.1	1,327.2	2,981.1	3,009.2	3,698.4
Number of people employed in hotels	13,615	18,283	23,252	26,495	29,082
Of which, women	7,463	10,347	13,111	14,394	15,512

The presented statistical data, which reflect the number of hotels, the total number and quality of rooms, the number of guests, including the dynamics of international visitors, and the number of employees in hotels in 2020–2024, indicate a positive correlation between the above indicators. The occupancy rate also shows a growing trend, which is actually an indicator of the growing dynamics of demand, regardless of the influence of seasonality. This result is consistent with the theoretical framework of sustainable tourism economics, according to which accommodation infrastructure is one of the determining factors of tourist demand. However, quantitative expansion does not always reflect an improvement in the quality of service. Despite the impressive results, a number of structural and systemic challenges have been identified that hinder the full development of the hotel business in Georgia. The hotel business in Georgia is significantly dependent on seasonality. Given that Georgia is a country of four seasons, the concentration of tourist flows in certain periods and regions increases the instability of income and complicates the process of long-term financial planning. This problem is especially acute for small and medium-sized hotels, which have limited financial resources. Seasonality requires diversification of the tourism product and the development of such segments as business tourism, ecotourism and cultural tourism.

At the same time, the role of the hotel business in the regional development process is noteworthy and especially visible. The development of the hotel business in the regions contributes to the growth and decentralization of economic activity, employment of the local population and the development of small businesses. These factors significantly increase the social effect of tourism and reduce the risks of economic inequality across the country. The issue of regional infrastructure also deserves attention. Despite the positive trends observed in recent years, transport accessibility, utility infrastructure and the development of digital services still remain a problem in certain regions. These factors limit the operational efficiency of hotels and reduce the attractiveness of certain regions for tourists. Without sustainable infrastructural development, sustainable development of the hotel business is impossible.

One of the main problems remains the shortage of qualified human resources. The quality of service largely depends on the professional skills of the staff, although the existing educational and professional training systems cannot ensure full compliance with market requirements. As a result, the level of service is often uneven, which negatively affects the overall experience of tourists.

The impact of global factors on the hotel business is another important aspect. The pandemic has clearly demonstrated the vulnerability of the sector to external shocks. A large part of hotels in Georgia have found themselves under financial pressure, which has highlighted the importance of crisis management strategies and risk management systems, which indicates that the hotel business should strengthen flexibility, use digital technologies and seek alternative sources of income.

Cooperation between the state and the private sector plays an important role in the development of the hotel business. Effective state policy, focused on promoting investments, simplifying regulations and introducing quality standards, contributes to the growth of the sector's competitiveness, and private sector initiatives in the direction of introducing innovations and improving the quality of service are critically important.

Conclusion: The hotel business in Georgia has a critical role in the Georgian tourism industry, as well as great potential for the implementation of sustainable management models. An important result of the hotel business is the sustainable and positive statistical growth, both in the hotel business and in the number of visitors. The main challenges still remain, however, regional imbalance, quality inequality and differences in service standards.

Taking into account all this, the focus of the state and hotel business policy should be directed in the following directions:

- Investments in regional infrastructure services;
- Strengthening higher and vocational training programs;
- Marketing and diversification strategies;
- Support for innovations and digital technologies.

The hotel business is the basis for the development of the Georgian tourism industry, however, the full realization of its potential depends on the effective resolution of existing challenges. Human capital development, infrastructure improvement, reduction of seasonality, increased resilience to crises, environmental responsibility, energy efficiency and use of local resources are the main directions that determine the future of the sector and are increasingly becoming a source of competitive advantage. However, this process critically needs both financial and institutional support.

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PUBLIC–PRIVATE PARTNERSHIPS IN SUSTAINABLE LOGISTICS INFRASTRUCTURE

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Abstract

The development of sustainable logistics infrastructure increasingly relies on effective public–private partnerships (PPPs) to balance economic, environmental, and social objectives. While traditional infrastructure planning prioritizes operational efficiency and financial returns, emerging frameworks emphasize the integration of sustainability and governance indicators to ensure long-term resilience and alignment with international development agendas. This study proposes a conceptual framework for assessing PPP-driven sustainable logistics initiatives. Drawing on key insights from Ahmadova and Mammadov (2025) and broader research on supply chain performance, governance, and sustainability, the framework highlights how PPPs can enhance strategic alignment, improve accountability, and facilitate measurable contributions toward global sustainability goals. Findings suggest that systematically embedding governance and sustainability metrics into PPP planning not only strengthens infrastructure effectiveness but also supports policy coherence and stakeholder engagement across complex logistics networks.

Keywords: Public–private partnerships, Sustainable logistics infrastructure, Governance, Supply chain performance, Sustainability metrics, Strategic alignment

Introduction

Public–private partnerships (PPPs) are key mechanisms for developing sustainable logistics infrastructure, particularly where public funding alone cannot meet growing demand for efficient and environmentally responsible transport systems (Akintoye, Beck, & Hardcastle, 2003; Yescombe, 2017). By combining public and private resources, PPPs aim to deliver infrastructure that meets operational and financial objectives while incorporating social and environmental considerations, aligning with sustainable development goals (Grimsey & Lewis, 2004; Hodge, Greve, & Boardman, 2017). Sustainable logistics infrastructure involves managing transport networks, warehousing, and distribution systems to minimize environmental impact, optimize resource use, and enhance social welfare (Rodrigue, Notteboom, & Slack, 2020; Van Wee, Annema, & Banister, 2013). PPPs provide a platform for integrating governance and sustainability indicators into decision-making, ensuring projects are accountable, transparent, and aligned with local and international agendas (Ahmadova & Mammadov, 2025; OECD, 2020). However, challenges such as data gaps, multi-stakeholder coordination, and inconsistent performance measurement may limit the ability of PPPs to achieve fully sustainable outcomes (Carter & Rogers, 2008; Seuring & Müller, 2008; Sarkis, Zhu, & Lai, 2011). Developing a conceptual framework that embeds governance and sustainability metrics into PPP planning is essential for ensuring long-term resilience, cross-sector accountability, and measurable contributions to global sustainability targets (World Bank, 2019; Ahmadova & Mammadov, 2025).

Literature Review

The literature on public–private partnerships (PPPs) and sustainable logistics infrastructure highlights the growing need to integrate economic, environmental, and social considerations into planning and management. Early studies focused on financial efficiency, risk allocation, and project delivery (Akintoye, Beck, & Hardcastle, 2003; Yescombe, 2017), often overlooking sustainability and governance dimensions crucial for long-term resilience and alignment with international development agendas (Grimsey & Lewis, 2004; Hodge, Greve, & Boardman, 2017).

Recent research emphasizes using PPPs not only to finance projects but also to embed sustainability indicators and governance frameworks into decision-making (OECD, 2020; World Bank, 2019). Ahmadova and Mammadov (2025) propose a framework integrating sustainability metrics into logistics performance, enhancing accountability, stakeholder engagement, and measurable contributions to social and environmental objectives. Sustainable logistics infrastructure involves managing transport networks, warehousing, and distribution systems to minimize environmental impact, optimize resource use, and enhance social welfare (Rodrigue, Notteboom, & Slack, 2020; Van Wee, Annema, & Banister, 2013). Embedding sustainability metrics in PPP projects can improve operational efficiency while addressing emissions, resource use, and community benefits (Carter & Rogers, 2008; Sarkis, Zhu, & Lai, 2011). Seuring and Müller (2008) note that translating

abstract goals into actionable indicators is essential for meaningful outcomes in complex logistics networks.Challenges remain in harmonizing sustainability measurement across diverse projects. Data gaps, multi-tiered supply chains, and inconsistent regulatory frameworks complicate metric implementation (Estache & Saussier, 2014; Flyvbjerg, 2014; Roumboutsos & Saussier, 2014). Effective cross-sector collaboration requires robust governance to ensure transparency, accountability, and alignment with development agendas (Carter & Rogers, 2008; Ahmadova & Mammadov, 2025).Overall, the literature suggests that strategically integrating sustainability and governance indicators within PPPs is critical for resilient, efficient, and socially responsible logistics infrastructure, improving transparency, stakeholder trust, and long-term effectiveness (World Economic Forum, 2022; OECD, 2020; Ahmadova & Mammadov, 2025).

Research Questions and Hypotheses

Based on the literature, key areas where PPPs can enhance sustainable logistics infrastructure include strategic alignment, sustainability metrics integration, governance mechanisms, and multi-stakeholder engagement (Ahmadova & Mammadov, 2025; OECD, 2020; Carter & Rogers, 2008). The study proposes the following research questions:

RQ1: How can PPPs systematically integrate sustainability and governance indicators into logistics projects?

RQ2: To what extent does embedding sustainability metrics in PPP projects improve operational efficiency and environmental performance?

RQ3: What governance and institutional factors support effective implementation of PPP-driven sustainable logistics initiatives?

Accordingly, the hypotheses are:

H1: PPPs incorporating sustainability and governance indicators positively influence strategic alignment in logistics projects.

H2: Embedding sustainability metrics within PPP operations enhances operational efficiency and environmental performance.

H3: Strong governance and institutional frameworks support effective implementation of sustainable logistics initiatives through PPPs.

Methodology

This study employs a qualitative, integrative approach to develop a conceptual framework for assessing PPPs in sustainable logistics infrastructure. A systematic literature review and framework synthesis were conducted using peer-reviewed articles, international reports, and policy documents to capture theoretical and practical insights (Ahmadova & Mammadov, 2025; Carter & Rogers, 2008; Seuring & Müller, 2008). The analysis identified convergent themes across PPP models, including sustainability indicators, governance mechanisms, risk allocation, and operational performance. Key metrics were mapped onto core logistics performance dimensions, enabling a framework that aligns PPP practices with sustainable development goals while addressing economic, environmental, and social objectives. By combining qualitative synthesis with cross-study comparison, the methodology provides a structured approach for designing and managing PPPs to deliver sustainable logistics infrastructure across diverse contexts (World Bank, 2019; OECD, 2020).

Results and Discussion

The analysis shows that PPPs enhance sustainability and efficiency in logistics infrastructure. Projects integrating governance and sustainability metrics improve strategic alignment, risk management, and accountability (Ahmadova & Mammadov, 2025; Carter & Rogers, 2008). Key performance areas include environmental impact, resource use, and stakeholder engagement (Rodrigue, Notteboom, & Slack, 2020). Embedding governance principles strengthens compliance with policies and reduces project risks (Seuring & Müller, 2008). Challenges remain in standardizing sustainability metrics across multi-tiered networks (Sarkis, Zhu, & Lai, 2011). Nonetheless, PPPs provide a scalable model for delivering sustainable infrastructure while enhancing transparency, stakeholder trust, and long-term resilience (World Economic Forum, 2022; Ahmadova & Mammadov, 2025).

Conclusion

Public–private partnerships (PPPs) play a critical role in advancing sustainable logistics infrastructure. Integrating governance and sustainability metrics enhances strategic alignment, accountability, and operational efficiency (Ahmadova & Mammadov, 2025; Carter & Rogers, 2008). The proposed framework demonstrates that embedding these indicators supports compliance with international development goals and strengthens stakeholder engagement. Challenges such as standardizing metrics and multi-tier coordination remain, but PPPs provide a scalable approach for resilient and socially responsible infrastructure. Future research should focus on quantitative validation and sector-specific implementation to optimize PPP outcomes in diverse logistics contexts (OECD, 2020; World Bank, 2019).

Materials

This study utilized peer-reviewed journal articles, international organization reports, policy documents, and sustainability standards to develop the conceptual framework. Emphasis was placed on studies providing empirical or theoretical insights into public–private partnerships, governance, and sustainable logistics infrastructure (Ahmadova & Mammadov, 2025; OECD, 2020; World Bank, 2019). Secondary datasets and existing performance indicators were analyzed to identify convergent themes for framework synthesis.

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MEDICAL SCIENCES

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR AMONG MEDICAL STUDENTS:AN IPAQ-BASED CROSS-SECTIONAL STUDY

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Abstract

Physical inactivity is a major modifiable risk factor for non-communicable diseases. Medical students, despite their future role as health promoters, are frequently reported to have insufficient physical activity and high sedentary behavior. This study aimed to assess physical activity levels, sedentary time, and gender differences among medical students using the International Physical Activity Questionnaire Short Form (IPAQ-SF). A cross-sectional study was conducted among 150 undergraduate medical students in 2025. Physical activity was assessed using the IPAQ-SF and expressed as metabolic equivalent task minutes per week (MET-min/week). Participants were categorized into low, moderate, and high physical activity groups according to established IPAQ criteria. Gender differences were analyzed using Welch's t-test and chi-square tests.

Keywords: physical activity; IPAQ; sedentary behavior; medical students; public health

Introduction. Insufficient physical activity is a leading modifiable determinant of non-communicable diseases, including cardiovascular disease, type 2 diabetes mellitus, and selected cancers [1,2-6]. In response, the World Health Organization (WHO) recommends that adults engage in at least 150–300 minutes of moderate-intensity aerobic physical activity or 75–150 minutes of vigorous-intensity activity per week, together with muscle-strengthening activities on two or more days per week [3,2]. Medical students represent a key population in preventive health. As future physicians, they are expected to counsel patients on lifestyle modification and disease prevention. However, growing evidence indicates that medical students themselves frequently fail to meet recommended physical activity thresholds and spend prolonged periods in sedentary behavior due to academic workload, stress, and time constraints [4-7,11,13]. Gender disparities have been consistently reported, with female medical students exhibiting lower levels of physical activity than males across different regions and cultural settings [8-12]. The International Physical Activity Questionnaire (IPAQ) is widely used in population-based studies and has demonstrated acceptable reliability and validity in young adult populations [13,14,3,5]. The short form (IPAQ-SF) allows standardized assessment of weekly physical activity volume using metabolic equivalent task units (METs), facilitating international comparison. This study aimed to assess physical activity levels, sedentary behavior, and perceived barriers among medical students using the IPAQ-SF, with a particular focus on statistically significant gender differences.

Purpose. Explanatory work to identify and define the lack of physical activity among the population, which is a consequence of the occurrence of various types of diseases.

Material and methods. A cross-sectional study was conducted during the 2025 academic year among undergraduate medical students. A total of 150 students participated voluntarily. The mean age was 20.5 ± 2.1 years. Females accounted for 65.3% (n = 98) and males for 34.7% (n = 52). The mean body mass index (BMI) was 22.4 ± 3.8 kg/m². Physical activity was assessed using the IPAQ Short Form, which captures frequency and duration of walking, moderate-intensity activity, and vigorous-intensity activity during the previous seven days. Weekly physical activity volume was calculated in MET-min/week using standard coefficients: walking = 3.3 METs, moderate activity = 4.0 METs, vigorous activity = 8.0 METs. Sedentary behavior was assessed as self-reported average daily sitting time (hours/day). Participants also reported perceived barriers to regular physical activity. Continuous variables are presented as mean ± standard deviation and categorical variables as frequencies and percentages. Gender differences in physical activity volume were evaluated using Welch's t-test. Associations between gender and physical activity categories were assessed using chi-square tests. Statistical significance was defined as $p < 0.05$. Participants were classified into three categories: •low physical activity (< 600 MET-min/week), •moderate physical activity (600–3000 MET-min/week), •high physical activity (> 3000 MET-min/week).

Results and discussion. According to tab.1, overall, 42.0% of students were classified as having low physical activity, 45.3% moderate activity, and only 12.7% high activity. According to tab.2, male students demonstrated significantly higher weekly physical activity compared with female students (2350 ± 1410 vs. 1450 ± 920 MET-min/week, $p < 0.001$). A significant association between gender and physical activity category was observed, with low physical activity being

more prevalent among females (p = 0.002). Mean daily sitting time was 7.2 hours. The most frequently reported barriers were lack of time (68%) and post-class fatigue (52%). This study demonstrates a high prevalence of insufficient physical activity and sedentary behavior among medical students. More than 40% of participants did not meet minimum WHO physical activity recommendations, consistent with findings from multiple international studies. A key finding is the pronounced and statistically significant gender disparity in physical activity, with female students exhibiting substantially lower weekly activity levels. Similar patterns have been reported in IPAQ-based studies across Europe, the Middle East, and South America, suggesting that this phenomenon is widespread and multifactorial.

Table1.

Participant characteristics

Characteristic	Value
Sample size	150
Age (years), mean ± SD	20.5 ± 2.1
Female, n (%)	98 (65.3)
Male, n (%)	52 (34.7)
BMI (kg/m²), mean ± SD	22.4 ± 3.8

Table 2.

Physical activity categories according to IPAQ-SF

Category	N	%
Low	63	42.0
Moderate	68	45.3
High	19	12.7

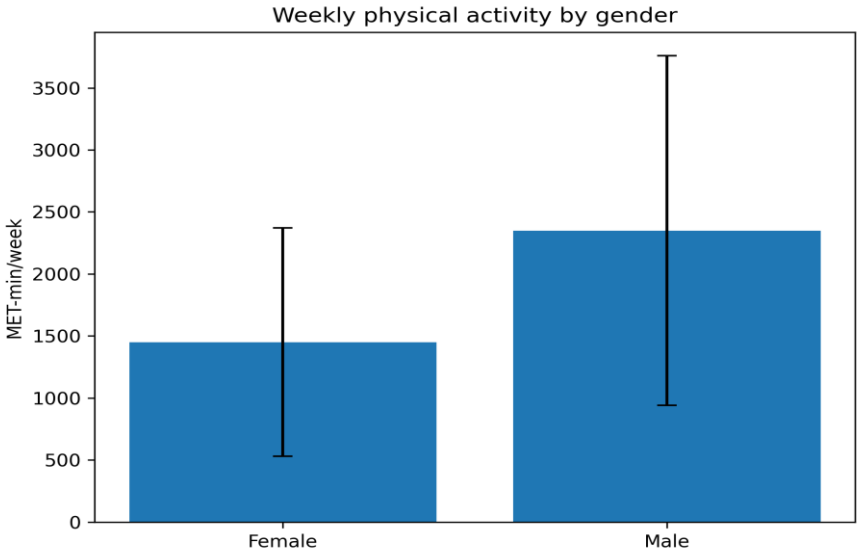

Figure. Weekly physical activity volume by gender (mean ± SD)

Results. The observed sedentary time exceeding seven hours per day is clinically relevant. Evidence increasingly indicates that prolonged sitting independently contributes to cardiometabolic risk, even among physically active individuals. WHO guidelines therefore emphasize both increasing physical activity and reducing sedentary behavior. Time constraints and academic fatigue were the dominant barriers reported, highlighting the need for institutional approaches rather than relying solely on individual motivation. Embedding physical activity promotion within medical curricula and providing accessible opportunities for exercise may improve adherence and foster long-term healthy behaviors among future physicians.

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PEDAGOGICAL SCIENCES

THE CURRENT STATE OF E-LEARNING, FUTURE TREND, WAYS TO MAKE IT SOPHISTICATED AND PERFECT, ITS SIGNIFICANCE AND RECOMMENDATIONS

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Abstract

Each country has its own educational system that depends on many factors such as language, culture, stage of development, demographics, and geographic location. These education systems have evolved and developed in accordance with the country's features and, thus, each country has its own unique educational system, though most countries share commonalities directly copied or slightly modified from each other. In the current globalized world, countries exchange experiences and collaborate on research to find better and more sophisticated education systems and implement the most effective ones. Today, people can travel anywhere around the world and, therefore, it is important to follow international teaching norms, creating the opportunity for people to participate in any training regardless of place, time, or distance. With the demands of the current developmental stage of society wherein artificial intelligence, electronic environment, and the fourth and even fifth industrial revolution prevail, it is essential to reconsider even long-held teaching strategies to match the demands of a rapidly changing present and swiftly approaching future.

In recent years, much has been made about various learning methods such as distance learning, online learning, and e-learning. In some cases, we began the initial stages of testing and introducing these new strategies but could only go so far without clear rules and regulations. But the world did not wait. It has been almost two years since the outbreak of the global pandemic, when all countries were forced to stop or reduce traditional classroom teaching and made to implement different forms of teaching such as electronic, distance, and telelearning, not only for elementary and high school students, but even for college and university students! However, it is evident that there are differences in the methods and quality of education, in learning, in grading, in attendance and participation of students, in the ability to learn independently, and in attitudes and evaluations of parents and the public. There are both good and bad aspects to e-learning. Therefore, this article aims to analyze the state of e-learning implemented at Mongolian University of Science and Technology (MUST) and make recommendations.

Keywords: e-learning, education, quality, performance, methods, evaluation, object

Current state: Electronic teaching has been conducted in accordance with the temporary regulations issued by the Education Policy and Regulation Department of MUST from the time when remote teaching began[1,4]. MUST published instructions on its web page, including an "E-learning web" portal where professors and instructors logged in with their usernames and IDs to upload their course files. The files could include lecture slides, lecture notes, lists of main and supplementary textbooks, self-exam questions for each lecture, midterm papers, assignments, etc. Every student can access this portal with his/her own student ID and study the course materials for the classes he/she is enrolled in, as well as communicate with instructors, submit questions, and view the instructors' answers, etc. In general, classes are taught according to a preset schedule wherein those with access to the internet, the necessary equipment, and can view the course online at that preset time, can directly connect with the instructor and attend the lecture online. Additionally, these students can connect with their instructors directly or indirectly at any time. The head of the department and the relevant personnel check the course files of individual instructors every time and make notes on required changes and/or improvements to individual files. Each instructor can track how students learn by accessing the statistical data available on the e-learning website (Table 1). Each instructor is required to report the e-learning progress of their students to their department head every week, who then compiles all the information and prepares an e-learning report (Table 2). It is further consolidated and reviewed at the level of constituent schools and MUST [1,5].

At the end of the semester, each instructor will award up to 70 points based on students' online assignments, tests, and their level of class participation, and 30 points based on their final exam. The final exam is also carried out according to the pre-given instructions and questions, either by directly answering the questions from the course instructor live at a preset time, or by taking an online test at a scheduled time. This is a general picture of how e-learning is going today. As is to be expected, e-learning has both strengths and weaknesses.

Strengths:

1. It is directed toward modern trends in education.
2. Each instructor's course materials are regularly reviewed, creating an opportunity to improve their content and quality.
3. There is an opportunity to instruct many people at the same time, independent of the capacity of a physical classroom, time, or location.
4. Students can interact with instructors and course files on a regular basis.

5. Results of exams and tests are protected from a certain level of interference.

6. Allows greater flexibility in location for both students and instructors.

Table 1

Check data to monitor how teachers teach their lessons.

№	Name of School	Student ID	Full name	Phone number, email address	Number of access	Total duration of access	Total time of studying	Average time of studying	Study time in a week

Table 2

Check data to monitor how students study their lessons.

№	Code of the course	Title of the course	Credit	Teacher ID	Teacher name	Number of enrolled students	Number of students who accessed in a week	Total time of access in a week	Attendance (%)

Weaknesses:

1. Some students have limited access to an online environment, whether due to lack of internet access or computer hardware.

2. A course file that has not been discussed by the team and does not fully meet the requirements might be posted.

3. It can be hard to track if students communicate with their instructors and access their course materials.

4. Access to the course is expressed only in quantitative terms, which is flawed from the qualitative point of view.

5. Increased ability for students to cheat on examinations and tests.

6. There are not as many proven and tested methods based on scientific research.

If the above-mentioned strengths and shortcomings can be so easily observed after little more than a year of observing e-learning, clearly it is necessary to carry out extensive research and analysis of e-learning issues on a wide scale involving many educational institutions. Scientific evaluation is required.

Quality of education, its components:

The most important outcome of e-learning should be the quality of learning. However, there is still no broad consensus on how to objectively quantify an educational outcome. Based on my forty years of research and experience working in higher education institutions, I believe that, first, we should develop a common understanding of how to evaluate quality levels. During my post-graduate studies at Moscow Mining University in Russia in 1989-1991, I learnt a lot about how to evaluate quality, what the quality evaluation indicators are, and how to select them. Using what I learnt, I earned my Doctor of Technical Science degree by carrying out research in “Assessment of the Quality Level of Mine Excavator Repair and Technical Service Systems” in 1991, and then my Doctor of Science degree on the subject of “Quality Management of Excavator Operations” at the Irkutsk Technical University in 1998. Because of that, I can confidently say that the problem of studying and evaluating the quality of any product, or service has a scientific basis[2,3].

Therefore, we must carefully consider the issues associated with evaluating the quality of education, especially e-learning: where to start, in what order, and how to quantify the quality. From this point of view, quality of teaching depends on quality of course files, which is a unit constituent of the teaching. Therefore, the quality of e-learning should be evaluated in the following order:

1. Rate the quality level of each course file - In other words, if the course file is of high quality, it implies the lesson quality will likewise be high. Now, of course, quality teaching depends not just on course files, but on the instructor and the students. Therefore, we must discover the cause of any quality weaknesses.

2. One of the main factors of quality education is the instructor. Even with a high-quality teaching file, if the instructor delivers the lesson poorly, does not enrich it, is unable to answer students’ questions, or is unable or unwilling to have a good relationship with students, student motivation is diminished, leading to poor educational outcomes.

3. Learning environment. The quality of e-learning depends on: (1) the capacity of the technical equipment used by the leading educational stakeholder or instructor, and the environment in which the teacher conducts e-learning, (2) internet, online environment, and hardware of the participating students or the receivers.

We must develop science-based methods to evaluate these components individually.

Theory and method for quantifying teaching quality

Any type of training is a service, and the quality of this service can and should be evaluated by the quality of the outcome, in this case, the quality of a student’s learning activity. In other words, the number of qualified graduates out of total graduates, or the number of graduates who are invited to work for certain companies. Evaluating the quality of education is a matter of choosing the correct indicator values for the object to

be evaluated and determining the degree to which their values are close to the values of the reference object or basic indicators. Therefore, the selection of basic reference parameters is the first task to be solved when assessing the quality of any product or service. To assess quality comprehensively, it should always be remembered that when choosing the total number of indicators, you should not choose indicators that are directly related to each other, because such indicators may contain the same information or meaning.

When selecting indicators for quality assessment, an indicator may not be selected if it does not have a significant impact on the outcome. Considering the rest of the indicators as defining indicators, it is necessary to select them as a set or combination of parameters for assessing the quality of work, services, and products. The independence of the parameters used in the comprehensive quality assessment makes it possible to use statistical, probabilistic, and mathematical methods for predicting the quality of products and services, for developing a specific method to evaluate, and for conducting research. The basic parameters for assessing the quality of objects with the same purpose must meet the following requirements:

1. be the best in terms of achieved levels by objects of the same type

2. help identify indicators that will play a key role in improving quality level

3. be able to change and/or evolve as provision of education becomes more sophisticated.

These requirements are met only by the model of the reference object, which consists of the parameters or baselines of such a level as are created for one of the objects of that type. Therefore, a benchmark object model is a mock model consisting of the best performance of various objects for the same purpose. It is more convenient to define the baseline parameters of the reference object model in percentage. Therefore, the percentage (X_{ij}) of parameters (indicators) (P_{ij}) selected to assess the quality of objects with the same purpose is determined by the following expression[2,3]:

$$X_{ij} = \frac{P_{ij}}{Q_i}$$

where i – sequence number of an object, j-sequence number of parameters or indicators, Q_i- main indicator of the *i*th object. Depending on the quality level of the object to be assessed, a matrix can be created with the parameters selected directly without defining the main indicators and individual indicators. An object can be defined as a specific item, product, or service. As mentioned above, the process of assessing the quality of teaching begins with assessing the quality of course files. Then after determining the values of individual parameters, they are entered into a matrix.

In order to make the method clear, consider the following example: when assessing the quality of a course file for a particular course, the evaluators are either the students or the teachers of the relevant major. These form the rows of the matrix. The scores from the evaluators form the columns of the matrix. In this way, we will be able to individually assess the file quality of all the courses taught by the department. It will then be possible to assess the quality level of all course files. At this point, the rows of the matrix are the subjects. Based on this principle, we can scientifically assess the quality level of course files, teachers, students, departments, etc., using the method below. If we choose real indicators and not personal metrics to make a quality assessment, then $P_{ij} = X_{ij}$:

$$X_{ij} = \begin{vmatrix} X_{11}X_{12} \dots X_{1j} \dots & X_{1n} \\ X_{21}X_{22} \dots X_{2j} \dots & X_{2n} \\ \dots\dots\dots & \cdot \\ X_{i1}X_{i2} \dots X_{ij} \dots & X_{in} \\ \cdot\cdot\dots\cdot\dots & \cdot \\ X_{m1}X_{m2} \dots X_{mj} \dots & X_{mn} \end{vmatrix}$$

The row of the matrix consists of the values of the eigenvalues of the *j*th parameter belonging to an object, whereas each column indicates the eigenvalue of one of the *j*th parameters of each object.

From each column of the matrix, the lowest (good) values of the percentage of quality indicators are selected and appropriate indices are assigned:

$$\{X_{cj}\} = |X_{c1,}X_{c2} \dots X_{cj} \dots X_{cn}|$$

The combination of base values provides a dynamic (moving) model of the reference object, which contains the best properties represented by the $\{X_{cj}\}$ metrics. If all X_{cj} values belong to the same object, the reference is a real model of the object. However, this is a very rare or almost non-existent case.

Subsequent comparisons are performed by comparing individual measures of quality indicators to baseline measures to other measures. The parameters are selected individually according to their impact on quality. If the opposite, their inverse should be taken. If positive and negative measures are necessarily selected for the quality assessment, the quality indicator is determined by assessing them separately and then finding the average. In this way, selecting the indicators chosen to evaluate the quality level and put them into a matrix form makes assessing the quality level of any product or service easy.

The quality level expressed in units of indicators (q_{ij}) or, in other words, separately for each indicator, is the ratio of the percentage of the basic parameters of the standard object (X_{cj}) to the same parameters of the object number i:

$$q_{ij} = \frac{X_{cj}}{X_{ij}} < 1$$

Quality unit indicators have no units of measurement and for any object they are always less than 1. The lowest (highest) or best indicators (X_{ij}) min, max are selected from the matrix, and (X_{ij}) min, max) $= X_{cj}$ for the reference machine. The X_{ij} value of any machine is close to its X_{cj} value, which means that it is equal to one or close to the best value. Therefore, the level of quality expressed in unit indicators is measured by the following expression for the reference object:

$$q_{cj} = \frac{X_{cj}}{X_{cj}} = 1$$

To determine the comprehensive quality level of the object by the combination of the quality levels expressed by the selected unit indicators, the coefficient indicating the ranking percentage of the quality level expressed by each unit indicator of the *i*th object must be determined. Therefore, when there are n parameters, the percentage (ranking) of the quality level expressed by each unit parameter of the object in their sum can be found by the following formula:

$$m_{ij} = \frac{q_{ij}}{\sum_{j=1}^{n} q_{ij}}$$

Percentage of quality level expressed per unit indicator for reference (model) objects:

$$m_{ij} = \frac{q_{cj}}{\sum_{j=1}^{n} q_{cj}} = \frac{1}{n}$$

The coefficient of participation (У_{ij}) of the quality levels expressed by each unit indicator in the general quality level of the object is determined by the following expression depending on the ranking percentage:

$$\text{У}_{ij} = \frac{1 - m_{ij}}{1 - m_{cj}}$$

The participation coefficient of the quality levels expressed by each unit indicator in the general quality level of the benchmark object is found by the following expression:

$$\text{У}_{cJ} = \frac{1 - m_{cj}}{1 - m_{cj}} = 1$$

The value of the sum of the quality levels expressed in unit indicators is determined by the sum of mean square method for the object number *i* by calculating their participation coefficient (У_{ij}) using the following formula:

$$\omega_i = \sqrt{\sum_{j=1}^{n} \left(\text{У}_{ij} q_{ij}\right)^2}$$

Value of the sum of quality levels expressed in unit indicators for reference objects:

$$\omega_c = \sqrt{\sum_{j=1}^{n} \left(\text{У}_{cj} q_{cj}\right)^2} = \sqrt{n}$$

The general (comprehensive) quality level of the object is equal to the ratio of the sum of the quality levels expressed by the unit indicators of the object to the sum of the quality levels of the reference object or is expressed as follows:

$$K_i = \frac{\omega_i}{\omega_c} = \sqrt{\frac{1}{n} \left(\text{У}_{ij} q_{ij}\right)^2}$$

With this methodology, we can not only assess the quality of the files for all courses, the quality level of teachers, and the quality level of all courses taught by the department, but also assess the quality of the course using a comprehensive scientific approach and many other methods can be used. As a result, based on this research, it will be possible to assess the teaching quality of the constituent schools of a specific university and of all national universities. Thus, based on the assessment derived by conducting science-based research, we can determine the current level of education quality, and develop a comprehensive understanding of how to improve the quality of education and prepare qualified staff in a success fostering environment.

Closing section:

Given our country's characteristics, the state of e-learning in the past, the need to improve e-learning in the future, and e-learning's positive and negative aspects, the following suggestions are presented:

The importance of e-learning and suggestions:

1. Students will have the opportunity to re-watch/listen to and read lectures. This provides a chance to reinforce their understanding and make connections with previous and subsequent lectures.

2. When preparing online lectures, five to six questions related to the content of the lecture must be prepared.

3. There is no need to create a designated time for exams. A set of questions for the exams are prepared from a group of lectures, and students take the exams online. Then the grades will be directly confirmed and entered into the system, where they will be combined and become the results of the semester exam. This has the advantage of making the exam fair and free from interference.

4. The issue of insufficient classroom capacity will disappear, allowing universities to seek alternate, potentially revenue-generating uses for them.

5. Lectures may be given only by the leaders of that major, and, in this way, minimizing the issues of inexperienced young teachers giving lectures and students rejecting or disrespecting their teachers. Young teachers will teach labs, seminars, and practical lessons in the classroom.

6. The quality of teachers will improve, and the requirements for teachers will increase dramatically. Teachers will be highly distinguished for their genuine competence, breadth of knowledge, enrichment of lectures, and use of examples.

7. As the number of teachers decreases, individual teacher salaries will increase.

8. Teachers are to be divided into two groups: (1) those who do lectures (professors with higher degrees) and (2) those who teach labs and seminars (lecturers without degrees). Since they will work together as a team, the concepts of part-time and contract teacher will disappear. The base salary fund will be determined by the total course credits the team teaches. In addition, pay increases will be based on a ranking.

9. There will be a unified laboratory at the entire university and rather than a teaching assistant overseeing the laboratory, an engineer-assistant teacher who is authorized to teach will be in charge.

10. The number of teaching assistants will be reduced.

11. For each major, a team of professors will be formed to work together to provide training on how to teach the courses of that major online and in the classroom.

12. As the classrooms are reduced to a certain level, the teachers' working conditions will improve, allowing them to devote more time to research and self-development.

13. Arrange classroom lessons to be held in the warm season rather than in the winter, allowing schools

to save money on electricity and heat. Also, update the study season in accordance with the climate and season.

14. As the procedure for calculating time loads radically changes and is updated and non-prevails, a team of teachers will be established, and collective responsibility will increase. A team with specific personnel will be responsible for the professional courses. Credit loads will be calculated jointly. Put an end to the issues of overtime pay. The quality of education will improve dramatically, as will teachers' ability to work as a team. Young teachers will experience the benefits of effective teamwork, improving their future skill levels.

15. The credits assigned to the lecturing teacher will not depend on the number of students. As the dependence on the number of students decreases, the transition from quantity to quality will begin, and, in the future, the number of students will decrease drastically, and only a few students with high quality and special learning skills will be admitted to MUST. The ability and quality of MUST graduates will increase, and the country's reputation alongside.

16. The ability to learn from anywhere will create an opportunity for foreign students to enroll. Laboratory courses may be taken at any school laboratory in the student's locale.

17. There will be additional cost savings as classrooms will no longer have to be equipped with expensive technologies.

18. In general, if courses are taught in classrooms in September-October and April-May, there will be huge savings in utilities during the winter season. Students from rural areas will have increased access to education. Student housing costs will decrease. The need for student accommodation will decrease.

19. With the possibility of working from home, teachers will have the opportunity to have side jobs. They will use their own computers, meaning the need to provide teachers with desktop and laptop computers will be reduced. Savings on expenses could contribute to increased salaries. The rank and salary of lecturers will be high. Therefore, those who have not yet earned academic degrees will be motivated to earn academic degrees. Anyone who has not earned their PhD degree within five years will be laid off. This will significantly increase the percentage of teachers with doctoral degrees in the school and increase the possibility of international recognition.

20. As the number of students decreases, this opens the possibility of condensing majors, avoiding the issue of having majors or departments with too narrow focus.

21. The need for paper will be ended by creating an electronic textbook collection. The capacity of the library will increase as the library and all its books will be electronic. A certain number of approved textbooks should be printed and archived.

22. All kinds of meetings and discussions will be conducted online and there will be no need to equip and maintain large conference rooms.

23. At the level of constituent schools, it will be possible to create joint laboratories between universities.

Conclusions:

1. E-learning has been implemented in the past and is currently being implemented as a necessary step that follows the modern trend of education. The fact that the educational institutions of our country are conducting the training in ways suitable for the level, without interrupting ongoing education as much as possible, is a reason to consider it as appropriate training for the times.

2. In the future, e-learning should be organized based on proper scientific evaluation at the appropriate quality level in accordance with modern trends and requirements, and the basis of clear rules and regulations. It should be officially confirmed as the most important form of education.

3. It is necessary to conduct a proper analysis of the results of e-learning by a wide group of qualified professional professors, scientists, researchers, and teachers with leading degrees and extensive work experience to have a clear understanding of e-learning at the national level.

4. One of the ways to continuously improve the quality of e-learning is to create a unit that conducts research on the improvement of e-learning at certain stages and regularly organize conferences and seminars to share experiences with the work being done in this direction.

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PHARMACEUTICAL SCIENCES

THE OPTİMİZATİON OF MEDİCİNAL PRODUCTS AND THE INFLUENCE OF ENVİRONMENTAL FACTORS ON DRUG EFFİCACY AND ADVERSE REACTİONS

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Abstract

The optimization of medicinal products represents one of the most complex challenges in contemporary pharmaceutical science. Although drug development traditionally focuses on chemical composition, dosage forms, and pharmacological activity, growing evidence indicates that environmental factors substantially influence drug efficacy, safety, and the occurrence of adverse drug reactions. Ecological conditions such as environmental pollution, climate variability, radiation exposure, and lifestyle-related stressors are capable of modifying pharmacokinetic and pharmacodynamic processes. These influences may result in reduced therapeutic effectiveness, increased toxicity, and unpredictable individual responses to pharmacotherapy. This article analyzes the mechanisms underlying adverse drug effects with special emphasis on environmental determinants, immune reactions, circadian rhythms, and individual variability. A comprehensive understanding of these interactions is essential for improving drug safety and developing personalized therapeutic strategies.

Keywords: drug optimization, environmental factors, adverse drug reactions, pharmacokinetics, chronopharmacology, bioavailability

Pharmaceutical science encompasses the development, production, quality control, storage, and rational use of medicinal products. In recent years, the concept of rational pharmacotherapy has expanded to include ecological and environmental determinants that significantly influence drug behavior in the human organism [1,2]. Despite advances in medicinal chemistry and biotechnology, adverse drug reactions remain a serious public health problem and are among the leading causes of morbidity related to pharmacotherapy [3].

Medicinal substances are derived from plant, animal, mineral, and synthetic sources. The environmental conditions under which medicinal raw materials are cultivated or extracted play a decisive role in determining their chemical composition and safety. Soil contamination, polluted water sources, industrial emissions, and pesticide residues may alter the qualitative and quantitative composition of biologically active compounds, thereby increasing the risk of toxic effects during clinical use [4].

Most drugs possess therapeutic benefits but may also induce undesirable side effects even when administered at recommended doses. Clinical observations indicate that adverse reactions occur in a significant proportion of patients receiving pharmacological treatment, with some cases requiring hospitalization and intensive medical care [7]. Environmental stressors such as chronic exposure to chemical pollutants, allergens, and heavy metals can intensify these reactions by impairing detoxification pathways and weakening immune defense mechanisms [1].

From a pathogenetic perspective, adverse drug reactions may arise due to overdose-related toxicity, poor drug quality, immune-mediated hypersensitivity, idiosyncratic responses, or withdrawal phenomena following long-term use. Environmental influences frequently act as triggering or aggravating factors by modifying metabolic enzyme activity and altering drug elimination processes [3].

Environmental pollution is a critical determinant of drug toxicity. Exposure to heavy metals and industrial chemicals may interfere with hepatic and renal functions, leading to drug accumulation and enhanced toxicity. Antibiotics and cytotoxic agents are particularly sensitive to such influences, as they may disrupt normal intestinal microflora and provoke dysbiosis, especially under conditions of contaminated food and water intake [5].

Immunological and allergic reactions to drugs are also strongly influenced by environmental conditions.

Although most drugs exhibit weak antigenic properties, long-term exposure to environmental allergens and pollutants may sensitize the immune system, increasing the likelihood of hypersensitivity reactions. These reactions may manifest as skin rashes, respiratory symptoms, or severe systemic responses such as anaphylaxis [2].

The timing of drug administration represents another important factor affecting drug efficacy and safety. Circadian rhythms regulate numerous physiological processes, including hormone secretion, enzymatic activity, and organ function. Disruption of these rhythms due to environmental or lifestyle factors such as shift work, irregular sleep patterns, seasonal changes, or climate conditions may alter pharmacokinetic parameters and increase the risk of adverse reactions [6].

Chronopharmacological studies demonstrate that administering drugs in accordance with biological rhythms can enhance therapeutic effectiveness while minimizing toxicity. Sedative and hypnotic agents tend to exhibit reduced toxicity during nighttime administration, whereas stimulant medications are generally more effective during daytime hours. These time-dependent variations highlight the importance of considering environmental and temporal factors in pharmacotherapy [6].

Individual variability further complicates drug response. Age, body weight, genetic predisposition, metabolic capacity, and environmental exposure history collectively determine drug tolerance and therapeutic outcome. Personalized pharmacotherapy that incorporates environmental risk assessment represents a promising strategy for reducing adverse drug reactions and improving treatment efficacy [1].

In conclusion, the optimization of medicinal products cannot be achieved solely through chemical and technological advancements. Environmental factors play a crucial role in shaping drug efficacy, safety, and individual response patterns. Integrating ecological considerations, chronopharmacology, and personalized medicine into pharmaceutical research and clinical practice is essential for developing safer and more effective therapeutic approaches.

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PHILOLOGICAL SCIENCES

THE PROBLEM OF RENDERING CULTURAL CONTEXT FROM DOSTOYEVSKY'S NOVEL THE BROTHERS KARAMAZOV INTO ENGLISH

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Abstract
The article is devoted to the problem of adequate translation of cultural context in the novel The Brothers Karamazov written by the great Russian writer of the 19th century Fyodor Dostoyevsky into English. The samples of cultural elements belonging to such linguistic categories as national realia, emotive words and phraseological units have been chosen from the two translations into English made by Constance Garnett and Richard Pevear followed by analysis, both stylistic and translation.

Keywords: cultural context, emotiveness, colloquialism, psychological tension, syntax, transformation.

Translation of any literary piece of text, be it a novel, a short story or a poem, pose a great challenge to translators, as along with the requirement for semantic equivalence of the translated text, the adequate rendering of all cultural and emotive elements is crucial. Cultural context consists of so-called lacunae, i.e., the words and phrases used by a specific nation at a specific time; they can include any lexical units that represent non-equivalent vocabulary reflecting specific cultural linguistic manifestations. When translating cultural context the general patterns of interaction between national language and culture are taken into account, as well as the specific problems of conveying the emotive and expressive qualities of the original text. The research representing the comparative analysis of culturally-bound utterances of the source and target texts should take into consideration "the phenomenon of lacunarity" in order to convey them appropriately in the target text, eliminating inadequacies which can lead to misunderstanding and losses of emotiveness and national colour [5, p. 1].

To analyze specific difficulties translators face when translating cultural context the literary heritage of Fyodor Mikhailovich Dostoyevsky can present a particular interest, as his prose written in an idiosyncratic language is full of national specific realia of the 19th century Russia. Dostoyevsky is one of the most influential figures in world literature, whose works cannot be fully understood without reference to the cultural, social, philosophical, and political context of 19th-century Russia. His novels reflect a society in crisis—torn between tradition and modernity, faith and doubt, Western influence and Russian national identity. Dostoyevsky's cultural environment profoundly shaped his worldview, themes, and artistic method. By engaging with the social upheavals, philosophical debates, and spiritual crises of his era, Dostoyevsky created novels that explore universal questions of freedom, faith, morality, and human identity. Understanding his cultural context allows readers to better appreciate both the historical specificity and the enduring relevance of his literary legacy.

Fyodor Dostoyevsky's novels are marked by a set of distinctive linguistic and stylistic features that make his prose immediately recognizable and, at the same time, notoriously difficult to translate. His language is inseparable from his philosophical depth, psychological intensity, and polyphonic narrative structure. While translating writer's prose it is of extreme significance to adequately convey the rich Russian cultural context, carefully handling cultural, historical, and geographical elements that might be unfamiliar to English readers. In this article we have undertaken an attempt to analyze the key linguistic peculiarities that characterize Dostoyevsky's fiction.

One of the most striking linguistic traits of Dostoyevsky's prose is the strong presence of oral, conversational speech. His prose often imitates spontaneous spoken language rather than polished literary narration. This is evident in broken sentence structures, repetitions and self-corrections, abrupt changes of topic or tone. Thus, the example of the main hero's emphatic repetition from *The Brothers Karamazov in* Russian though sounds unnatural, is possible:

«Я подлец, подлец я, подлец! Но не вор я, не вор!»

In typical English translation repetition is preserved to retain the colloquial way of oral speech and psychological tension of the character. Translators usually try to convey this stylistic device, although in English, repetition risks sounding theatrical or excessive, yet removing it weakens emotional volatility:

"I am a scoundrel, a scoundrel, I admit it! But I am not a thief, not a thief!"

On the whole, repetition as a stylistic device is a key feature of Dostoyevsky's language. Words, phrases, and ideas are reiterated obsessively, sometimes within a single paragraph. This serves the functions of emphasizing psychological fixation, mirroring inner monologues and obsession, creating rhythmic and emotional intensity.

While such repetition may seem stylistically "inelegant" by classical standards, it is a deliberate artistic choice that reinforces the emotional state of his characters. As is seen from the example, the stylistic repetition

conveys emotional agitation and psychological instability [1, p. 211]. From a linguistic perspective, such colloquial manifestation of character's speech blurs the boundary between written and spoken discourse.

It is generally acknowledged that Dostoyevsky's language contains the vocabulary typical to the 19-th century Russian diction, as in the example of Alyosha's emphatic words after Zosima's death**:**

«Он пал на землю… он пал и целовал её…» -

"He fell to the ground… he fell and kissed the earth…"

The repetition of the noun *"пал"* which is a poetic word signals emotional shock and ritual humility. The translator opted to use the neutral lexical unit "*fell"*. A synonym replacement of such words as *"collapsed"* or *"knelt"* would reduce the symbolic force of the utterance. The literal repetition of both source and target texts is stylistically justified, even if it can sound a little untypical for English.

The idiosyncratic element of Dostoyevsky's style is also manifested through an extreme syntactic complexity and irregularity. The author frequently uses long, overloaded sentences combined with sudden short, exclamatory ones. His syntax often appears chaotic due to multiple subordinate clauses, dashes instead of clear punctuation, parataxis replacing logical subordination. This syntactic irregularity reflects the uneven, fragmented consciousness of his characters. Rather than guiding the reader smoothly, Dostoyevsky forces them to experience confusion, tension, and inner conflict through purely linguistic means. The irregular syntactic structures are permeated by the specific irregularity of voices and narration, resulted in polyphony and speech diversity.

Dostoyevsky's polyphonic style means multiple independent voices coexisting without being subordinated to the author's own ideology. Linguistically, this results in sharply differentiated idiolects (individual speech styles), contrasting registers (from philosophical discourse to street slang), ideological conflicts embedded in dialogue rather than narration. Each character speaks in a way that reflects their social background, education, and worldview, making dialogue a central carrier of meaning. For example when Ivan Karamazov expresses his philosophical ideas on religious issues:

«Если Бога нет, то всё позволено, и тогда, стало быть, человеку не на что опереться…» "If God does not exist, then everything is permitted, and then, it would seem, man has nothing to rely on…"

While syntax of Russian sentences permits long chains of logical connectors (*"и тогда, стало быть"*), English tends to simplify or segment such structures. The translator of this sentence tried to keep the heaviness of Ivan's reasoning without over-clarifying it. Mixing of registers and styles is a characteristic feature of Dostoyevsky who often combines high philosophical language with colloquial, even crude expressions within the same text—or even the same sentence. This stylistic heterogeneity reflects the social stratification of Russian society. It also heightens dramatic contrast, reinforces the theme of moral and spiritual conflict. Normally an English text usually balances colloquial and informal tone. Meanwhile, as we can witness, over-elevating the speech tone underlines Dostoyevsky's stylistic intention of oral speech characterization the main heroes use. For translators such mixture poses a challenge, as preserving both stylistic contrast and naturalness in the target language is a challengeable matter. Such polyphony, i.e., differentiated voices can be witnessed in comparison of Ivan's speech which is syntactically complex and abstract and Alyosha's simple and ethical language:

«Я не Бога не принимаю, я мира, им созданного, не принимаю.» -

"It's not God that I don't accept, but the world He created, that I do not accept."

«Это бунт.»

"That's rebellion."

The second sentence represents Alyosha's reply which is minimalistic and morally loaded. Translators managed to preserve contrast, not stylistic uniformity, and it leads to the adequate translation.

Dostoyevsky was one of the pioneers in representing inner speech that marks the psychological depth of his characters. Their thoughts often appear unstructured, contradictory, and emotionally unstable. Linguistically, this is achieved through unfinished sentences, rhetorical questions, sudden shifts from narration to internal monologue. This technique anticipates later developments in modernist literature and stream-of-consciousness narration. The example of such inner speech and fragmentation is clearly obvious in Ivan's speech who suffers mental collapse:

«Нет, невозможно… чёрт возьми, да ведь это вздор!» -

"No, impossible… damn it, it's nonsense!"

The extremely grave psychological state of the character results in abrupt emotional shifts where colloquial exclamations interrupt the smoothness of thought. Nevertheless, in translation punctuation and rhythm are crucial; smoothing the text would erase Ivan's breakdown.

Apart from the words belonging to the Russian language of the 19-th century, Dostoyevsky's vocabulary is highly emotional and evaluative in character. The language of the characters is heavily charged with emotional stylistic devices, both lexical-syntactic, and phonetic prosodical features, sometimes expressed graphically. The evaluative meaning is felt when we see that the characters constantly judge, accuse, justify, and contradict themselves. Such meaning is achieved by frequent use of modal words, intensifiers, and emotionally loaded adjectives; it contributes to heightened expressiveness, moral tension, a sense of urgency and crisis. Russian evaluative adjectives and adverbs usually carry strong moral and religious resonance; and language itself becomes a tool of ethical struggle. For example, Dmitry's confession of moral guilt risks sounding legal rather than existential. The translator reinforced intensity through rhythm and repetition:

«Я виновен, я виновен во всём!»

"I am guilty, guilty of everything!"

The most remarkable linguistic area that requires analysis is the specific cultural words, very frequently, realia. In this paper we would only like to present some of such linguistic units and compare two versions of

their translations, those of Constance Garnett and Richard Pevear. Such cultural concepts may include:

Russian measures *(verst) ("верстах в двух")* translated by the calque and adaptation - *"about a mile away"*; cultural concept: *"тоска" ("тоска по...")* translated by borrowing + explanation *"toska" - "a deep longing for..."*. For example, such Russian word as *"юродство" (yurodstvo)* which means "foolishness for Christ's sake" was translated as:

- Garnett: *"holy fool"* (adaptation, conveys spiritual aspect)

- Pevear: *"fool for Christ"* (closer to the original, explicit reference)

As we see Pevear's version keeps the direct link to Christ, emphasizing the religious motivation. Garnett's *"holy fool"* is more general but widely understood in English.

Realia:*"кабаки" (kabaki)* with the meaning of taverns or inns presented such translations:

- Garnett: *"tavern"* (common English equivalent)

- Pevear: *"drinking house"* (literal, conveys basic meaning).

Analyzing the two translations we should stress that the version *"tavern"* used by Garnett feels more natural in English; *"drinking house"* (Pevear) which is translated by the descriptive method is straightforward but less common.

Translation of some more realia can include such a cultural concept *"старцы" (starcy)* - elders/spiritual advisors in the following sentence:

"Он пошел к старцу Зосиме." - "He went to the elder Zosima."

- Garnett: "He went to the Elder Zosima." Translated by borrowing "Elder".

- Pevear: "He went to Father Zosima, "the starets." The translator used the calque "starets", written by transliteration with the explanation.

Translation of slang: *"подлец"* (podlec - scoundrel/bastard).

- Garnett: *"scoundrel"*. The translation is more polite the insult is formal. It is milder but captures the contempt.

- Pevear: *"bastard"* sounds definitely much stronger, cruder and moderately vulgar.

Russian customs also represent cultural concepts difficult to convey into English. Thus the Russian custom *"Хлеб-соль" - bread-salt* represents a symbol of hospitality.

The original phrase from the novel *"принять хлеб-соль"* ("to accept bread and salt") translated slightly differently:

- Garnett: *"partake of bread and salt"* is more or less literal.

- Pevear: *"share bread and salt"* is translated with the use of lexical replacement and it retains cultural hint.

Geographical reference means cultural context as well, such as:

"из русских немцев" - from Russian Germans.

- The original sentence sounds very unclear to the English-speaking readers:

"Он был из русских немцев."

- Garnett: *"He was a Russian German."* The literal translation can definitely confuse the target readers, it is not clear.

- Pevear: *"He was one of the Russian Germans."* The clarified translation supposes the group identity, the translation contains explanation.

The emotional concept which represents abstract notion, although existing in all language communities, is linguistically expressed differently in different languages: *"надрыв"* (nadryv - intense emotional strain/breaking point).

The original sentence: *"Это был надрыв."*

- Garnett: "It was a breaking point." The translation used adaptation with the transformation on the phrase level.

- Pevear: *"It was a rupture."* The calque used in the target sentence is closer to the original, though it is not a full equivalent.

As we see, the tendencies the two translators resort to differ. While Garnett often chooses more familiar to the target readership correspondences, Pevear tends toward fidelity to the original terms, using the same tone, sometimes with slightly formal, even archaic or poetic English.

Thus, Dostoyevsky's linguistic peculiarities — oral syntax, repetition, polyphony, stylistic heterogeneity, and psychological intensity are not accidental flaws but essential components of his artistic method. His language is deliberately strained, unstable, and emotionally charged, mirroring the existential crises of his characters. For readers and translators alike, engaging with Dostoyevsky means confronting a form of language that challenges norms in order to reveal deeper psychological and philosophical truths. Therefore, in order to convey the cultural context correctly, with the adequate correspondence of syntax, stylistic devices, repetition including the voice, apart from vocabulary, the translators have to use a number of transformations, such as calque, replacements, adaptation, explanation, etc.

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TECHNICAL SCIENCES

PASSENGER FLOW AND ITS STUDY

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Abstract

The article is devoted to the essence of passenger flow, the mechanisms of its formation, and the issues of its study on a scientific basis. The acceleration of modern urbanization processes, the increase in population density, and the growing complexity of transport infrastructure make accurate analysis and forecasting of passenger flows essential. Passenger flow is one of the key indicators that determine the efficiency of the transport system, the optimization of timetables, the proper distribution of carrying capacity, and the assurance of socio-economic development.

The article explains the concept of passenger flow within the context of transport science and systematizes its main types, including daily, seasonal, and peak-hour flows, as well as flow patterns differentiated by direction. The factors influencing the formation of passenger flow—such as population size and spatial distribution, the location of employment and educational centers, the structure of the transport network, tariff policy, social behavior, and the level of urbanization—are analyzed in a comprehensive manner.

The study provides a detailed discussion of the methods used to examine passenger flows. These methods include statistical observation, surveys and questionnaire techniques, automated counting systems, analysis of ticket sales data, digital technologies, and modeling approaches. Particular emphasis is placed on the expansion of opportunities for real-time monitoring and forecasting of passenger flows as a result of the application of information and communication technologies.

The article also highlights the practical significance of accurately studying passenger flows. This is crucial for improving route networks, optimally selecting the number and capacity of vehicles, regulating service intervals, reducing congestion, and enhancing passenger comfort. Ultimately, the scientific study of passenger flows is regarded as a decisive factor in the formation of a sustainable transport system and in improving the quality of urban life.

Keywords: passenger flow, transport system, passenger transportation, transport planning, statistical analysis, route network, urban transport, monitoring, modeling, forecasting

Transportation systems play a vital and indispensable role in the socio-economic development of modern society. The intensification of economic activity, the acceleration of urbanization processes, the growth of population mobility, and the expansion of connections between residential areas and centers of employment, education, and services have significantly increased the demand for transportation systems. In this regard, transportation is not merely a technical means of moving people from one location to another, but also functions as a strategic factor that determines the socio-economic development of cities and regions (Giuliano, G., & Hanson, S., 2017).

The effective operation of transportation systems is closely linked to the proper organization and scientifically grounded study of passenger flows. Passenger flow represents the quantitative and structural characteristics of people's movements within a certain time and space using various modes of transport. This concept is considered one of the key indicators characterizing the dynamism of urban life, the rhythm of the population's daily activities, and the functional load of public spaces. The intensity and directionality of passenger flows are directly related to the level of employment, social behavior, economic activity, and urban planning characteristics of the population.

The analysis of passenger flows is of particular importance for the planning of transport infrastructure, the rational design of route networks, and the determination of the number of vehicles and their operating intervals. At the same time, such analysis serves the goals of minimizing passengers' time losses, reducing transportation costs, and improving service quality. Especially in large cities and urban agglomerations, the uneven distribution of passenger flows leads to a number of negative consequences, such as traffic congestion, environmental problems, and social discomfort, which makes the scientific investigation of this issue essential.

The study of passenger flow is regarded as one of the key directions of modern transport policy and has significant methodological and practical importance in ensuring the sustainable development of transport systems (Fruin, J. J.,1971).

Passenger flow, as one of the fundamental concepts in transport science, refers to the number of passengers transported along a specific transport route, direction, or transport network within a given time interval. This concept encompasses not only the quantitative indicator of passengers but also their movement trajectories, temporal distribution, and the intensity of transport mode usage. Passenger flow serves as a key indicator that makes it possible to assess the degree of

load on a transport system at the urban and regional levels (Gwilliam, K. M.,1999).

The study of passenger flow constitutes one of the central analytical approaches for understanding both the quantitative and structural characteristics of transport systems. In scientific analysis, passenger flow is defined as the number of passengers passing through a specific route, stop, or segment of a transport network within a given time interval and is commonly expressed by the formula

$$Q = \frac{N}{t}.$$

This expression establishes the basic relationship between transported passengers and time, allowing researchers to evaluate the actual operational load of a transport system. Despite its simplicity, this formula forms the foundation for more complex analytical and graphical interpretations of passenger movement dynamics.

When passenger flow is observed over time, it becomes evident that it should not be treated as a constant value but rather as a time-dependent process. This temporal variability is usually illustrated through time–flow diagrams, where the horizontal axis represents time and the vertical axis represents passenger volume. Such diagrams clearly demonstrate the presence of peak and off-peak periods, with sharp upward slopes during morning and evening hours and flatter segments during midday. The average passenger flow across multiple time intervals is calculated as

$$\bar{Q} = \frac{1}{n}\sum_{i=1}^{n} Q_i,$$

and is often depicted on the same diagram as a horizontal reference line. However, the visual contrast between this average line and the actual fluctuating curve reveals that the mean value alone does not adequately describe system behavior.

To capture the extent of these fluctuations, dispersion analysis is applied, defined mathematically as

$$D = \frac{1}{n}\sum_{i=1}^{n} (Q_i - \bar{Q})^2.$$

In graphical terms, high dispersion corresponds to wide vertical deviations of the passenger flow curve from the average line. Such diagrams highlight instability in demand and visually justify the need for flexible scheduling and reserve transport capacity during periods of heightened variability.

Spatial analysis of passenger flow relies heavily on Origin–Destination relationships, which are most effectively represented through matrix diagrams. The Origin–Destination matrix is expressed as

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix},$$

where each element a_{ij} denotes the number of passengers traveling from origin i to destination j. When this matrix is visualized as a heat map or shaded diagram, the diagonal elements a_{ii} appear as a distinct visual axis. These diagonal values represent internal or local movements within the same zone. A dominant diagonal visually signals that short-distance trips prevail, while intensified off-diagonal shading indicates strong inter-district or inter-urban mobility. Thus, diagonal-oriented diagrams provide immediate insight into the functional structure of passenger movement.

Network-based passenger flow is commonly illustrated through flow diagrams derived from graph theory. In such diagrams, transport stops are represented as nodes and routes as edges, with edge thickness proportional to passenger volume. The analytical condition governing these flows is

$$f(e) \le c(e),$$

where $f(e)$ denotes the actual passenger flow on a route segment and $c(e)$ its carrying capacity. Diagrammatically, violations of this condition are shown by excessively thick edges, visually indicating congestion points within the network. These diagrams are particularly effective in identifying critical bottlenecks and structurally weak links.

Uneven distribution of passenger flow over time is further examined using the peak load factor

$$k_p = \frac{Q_{\max}}{\bar{Q}}.$$

This coefficient is often visualized through bar charts or comparative diagrams where peak-period columns significantly exceed the average level. Such visual disparities emphasize the concentration of demand within limited time windows and reinforce the necessity for adaptive timetable and fleet management strategies.

In forecasting analysis, passenger flow is treated as a function of time and graphically represented through trend diagrams. A basic linear forecasting model is expressed as

$$Q(t) = a + bt,$$

where the slope of the line reflects long-term growth tendencies. When seasonal or cyclical variations are included, the resulting diagram takes on a wave-like form, illustrating periodic increases and decreases around the trend line. These diagrams allow planners to visually assess future demand patterns and align infrastructure development accordingly.

In conclusion, the enrichment of passenger flow analysis with formulas, matrix diagonals, and diagrammatic representations enables a deeper and more structured understanding of transport system behavior. Time–flow curves, diagonal-dominant matrices, network flow diagrams, and forecasting graphs together form a coherent analytical framework. This integrated approach not only clarifies the current operational state

of transport systems but also supports scientifically grounded decision-making aimed at improving efficiency, reliability, and long-term sustainability.

The formation of passenger flow varies across different times of the day. In particular, peak flows observed in the morning and evening hours are closely related to people's work activities, commuting to and from educational institutions, and social lifestyles. While passenger flow tends to be relatively stable and high on weekdays, it decreases on weekends and public holidays, when trips are more often associated with leisure, shopping, and recreation. Seasonal factors—especially the summer and winter periods—as well as increases or decreases in tourist flows also have a significant impact on the volume and structure of passenger flow.

Socio-economic factors are considered among the main determinants of passenger flow formation. Population size and density, employment levels, the functional zoning of the city, income levels, and transport tariffs determine the intensity and direction of passenger flow. In addition, the availability of alternative modes of transport, the number of private vehicles, and the level of development of road infrastructure are among the important indicators influencing the variability of passenger flow.

One of the main characteristics of passenger flow is its uneven distribution. This unevenness manifests itself in both temporal and spatial terms. Flows directed toward city centers are usually more intensive, while a relative decrease is observed in peripheral residential areas. The directional nature of passenger flow defines its main movement vectors and plays an important role in route planning (Hensher, D. A., Rose, J. M., & Greene, W. H.,2015).

Although continuity denotes the relative stability of passenger flows over a certain period of time, this stability is not entirely immutable. Economic crises, natural events, epidemic conditions, or urban planning decisions can cause abrupt changes in the structure of passenger flows. It is precisely this variability that necessitates the design of transport systems based on flexible, adaptive, and predictable mechanisms.

The scientifically grounded study of the concept of passenger flow and its main characteristics is of fundamental importance for the efficient organization of transport systems, the optimal use of resources, and the обеспечение of passenger comfort.

The primary objective of studying passenger flows is the scientifically substantiated identification of actual and potential demand for the transport system. This process makes it possible to assess the actual load on the existing transport network, analyze passengers' daily movement directions, their temporal distribution, and the intensity of transportation. At the same time, on the basis of the conducted studies, the future impact of factors such as demographic growth, the expansion of urban areas, and the formation of new residential and industrial zones on passenger flows can be forecast (Jansson, J. O.,1980).

The systematic study of passenger flows ensures the rational design of transport routes, the optimization of existing routes, and the identification of alternative travel directions. This creates conditions for aligning the number of vehicles with real demand, properly regulating service intervals, and improving passenger comfort during the transportation process. As a result, passenger waiting times are reduced, while the operational efficiency of transport vehicles increases.

At the same time, the analysis of passenger flows makes it possible to determine the level of load on road and transport infrastructure. The causes of congestion during peak hours are investigated, the mechanisms behind the formation of traffic jams are revealed, and scientifically grounded measures for their mitigation are developed. In this regard, the study of passenger flows plays an important role in balancing urban transport flows (Dickey, J. W. ,1975).

Accurate assessment of passenger flows is of particular importance from an environmental perspective as well. The optimal operation of transport vehicles contributes to a reduction in harmful emissions released into the atmosphere, minimizes fuel consumption, and alleviates the ecological burden on the urban environment. This, in turn, is considered a crucial prerequisite for the implementation of sustainable development and "green transport" concepts.

Especially in large cities and urban agglomerations, the study of passenger flows serves as a fundamental scientific basis for shaping urban transport policy. Based on the results of conducted studies, long-term development strategies, transport infrastructure projects, and socially oriented decisions are formulated. Thus, the analysis of passenger flows emerges as an important scientific and practical field that serves not only the transport sector but also the functional, safe, and sustainable organization of urban life as a whole (Kittelson & Associates, Inc., 2013).

The study of passenger flows is one of the key stages in the planning and management of transport systems. For this purpose, the applied methods are conventionally divided into two main groups: traditional methods and those based on modern technologies. Both groups of methods aim to determine the intensity and direction of passenger movements, their temporal distribution, and the characteristics of transport mode usage.

Traditional methods include visual observation, passenger counting, and survey techniques. The visual observation method is based on the direct monitoring of boarding and alighting processes of passengers at specific stops and along particular routes and is mainly used in short-term studies. The counting method involves recording the number of passengers boarding and alighting from vehicles. This method makes it possible to identify route load levels, peak hours, and vehicle occupancy rates. Survey methods, in turn, are used to examine passengers' travel purposes, route choices, travel frequency, and attitudes toward service quality, which is of significant importance for analyzing the influence of social factors on transport flows.

At the same time, traditional methods of studying passenger flows have a number of inherent limitations. These approaches generally require substantial time and labor resources and often fail to ensure the timeliness, accuracy, and completeness of the collected data.

Manual surveys, visual counts, and periodic observations are typically episodic in nature and therefore do not fully reflect the dynamic and continuously changing characteristics of passenger movement. For these reasons, in the modern era, methods based on information and communication technologies (ICT) have become increasingly preferred in the analysis of passenger flows (Kuznetsov, V. M., 2005).

Among contemporary approaches, electronic ticketing systems occupy a particularly important position. Through these systems, it becomes possible to obtain precise and reliable statistical data on passenger boarding times, travel routes, fare usage, and the intensity of transport service utilization. Such data allow researchers and transport authorities to analyze demand patterns, peak-hour loads, and spatial–temporal variations in passenger movement with a high degree of accuracy. As a result, electronic ticketing serves not only as a payment mechanism but also as a powerful analytical tool for transport planning and management.

GPS technologies further enhance passenger flow analysis by enabling real-time tracking of vehicle movements. These technologies make it possible to assess actual route occupancy levels, travel speeds, delays, and adherence to schedules. The integration of GPS data with geographic information systems (GIS) facilitates the visualization and spatial analysis of transport flows, contributing to more informed decisions regarding route optimization, timetable adjustments, and infrastructure development (Meyer, M. D., & Miller, E. J., 2001).

In addition, data obtained from mobile network operators play an increasingly significant role in passenger flow research. By analyzing anonymized and aggregated location data, it becomes possible to identify passengers' movement trajectories, daily migration patterns, and urban mobility models. This approach provides valuable insights into commuting behavior, inter-district travel demand, and the functional structure of urban space, which are difficult to capture through traditional survey-based methods alone (Daganzo, C. F.,1997).

Video surveillance systems and automated recognition technologies also allow for highly accurate assessment of passenger flow intensity and variability. When integrated with artificial intelligence and machine learning algorithms, these technologies enable the modeling and forecasting of passenger behavior, including crowd formation, boarding and alighting patterns, and responses to service disruptions. Such systems are particularly effective in high-density environments such as metro stations, terminals, and major transfer hubs (Ceder, A.,2007).

As a result, the processing and analysis of large-scale datasets (Big Data) ensure the optimization of transport systems, the improvement of route networks, and the implementation of evidence-based decision-making processes. The comprehensive application of passenger flow research methods is therefore of great scientific and practical importance, as it contributes to the efficient management of transport systems, the rational use of resources, and the enhancement of passenger satisfaction and service quality.

Conclusion. Passenger flow is one of the key indicators that determine the functional efficiency of a transportation system, while simultaneously serving as an important factor reflecting the level of socio-economic development of cities and regions. The intensity of passengers' daily movements, their directional patterns, and temporal distribution reveal the actual demand placed on transport networks. Accurate assessment of this demand is possible only through scientifically grounded research methods. In this context, the study of passenger flow enables an objective evaluation of the current state of the transportation system and facilitates the identification of weak points and problematic areas that hinder its effective operation.

Research on passenger flow plays a crucial role in the planning and development of transport infrastructure. The optimization of route networks, the appropriate selection of vehicle capacity and fleet size, and the adjustment of service schedules to match passenger demand are all fundamentally based on the results of such analyses. As a consequence, these measures contribute to reducing passengers' travel time losses, minimizing congestion within vehicles, and improving the overall quality and reliability of transport services. Efficient passenger flow management also enhances system resilience under peak demand conditions and supports balanced spatial mobility within urban environments.

The integration of modern information and communication technologies into the transport sector has ushered in a qualitatively new stage in the study of passenger flows. Electronic ticketing systems, digital monitoring tools, and big data analytics make it possible to track passenger flow dynamics with greater precision and to generate both short-term and long-term forecasts. Data obtained through these technologies support evidence-based decision-making in transport management, allowing for flexible operational adjustments and the development of sustainable transport strategies that respond to changing mobility patterns (Ben-Akiva, M., & Lerman, S. R.,1985).

In conclusion, the continuous, systematic, and comprehensive study of passenger flow should be regarded as one of the primary priorities of contemporary transport policy. This approach not only enhances the efficiency and effectiveness of transportation systems but also contributes to environmental sustainability, improves social comfort, and plays a significant role in raising the overall quality of life of the population. By aligning transport planning with real passenger demand, cities and regions can achieve more sustainable, inclusive, and user-oriented mobility systems.

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ANALYTİCAL IDENTİFİCATİON AND INTELLİGENT CONTROL OF EMERGENCY MODES İN PARALLEL GAS PİPELİNES BASED ON IOT MONİTORİNG

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ИДЕНТИФИКАЦИЯ И АВТОМАТИЗИРОВАННОЕ УПРАВЛЕНИЕ АВАРИЙНЫМИ РЕЖИМАМИ В ПАРАЛЛЕЛЬНЫХ ГАЗОПРОВОДАХ НА ОСНОВЕ IOT-ТЕХНОЛОГИЙ

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Abstract

This study proposes an analytically driven framework for the detection and control of emergency operating conditions in parallel gas pipeline networks supported by real-time digital monitoring. The approach addresses the limitations of purely sensor-based supervision by incorporating gas-dynamic analysis into the decision-making process, which allows a clear distinction between normal operational transients and emergency-induced disturbances.

A pressure-based analytical condition is formulated for emergency recognition using inlet and outlet measurements, followed by a physics-oriented method for estimating the location of gas leakage without deploying additional sensing equipment. In addition, a time-dependent control rule is derived for the activation of interconnecting pipeline valves, accounting for compressor station dynamics in order to restore system stability and preserve the integrity of unaffected pipeline lines.

The proposed solution is structured as an automated feedback control scheme compatible with SCADA architectures and IoT environments. Its implementation enables a reduction in gas losses, operational uncertainty, and system vulnerability, while supporting the transition toward digitally managed gas transmission infrastructures.

Аннотация

В статье предложена методология идентификации и эффективного управления аварийными режимами в многолинейных параллельных газопроводах на основе интеграции технологий Интернета вещей (IoT) и аналитических газодинамических моделей. Показано, что применение исключительно цифрового мониторинга не обеспечивает достаточной надежности при различении технологических и аварийных режимов эксплуатации газопроводов.

В работе разработан аналитический критерий идентификации аварийных процессов на основе анализа временных изменений давления на входе и выходе газопровода. Предложен метод оперативной локализации места утечки без использования дополнительных датчиков, основанный на аналитической обработке данных IoT-сенсоров. Также получено выражение для определения оптимального момента включения соединительных трубопроводов, обеспечивающего стабилизацию режима работы системы и непрерывность газоснабжения потребителей.

Предложенная методология может быть реализована в диспетчерских центрах и интегрирована в SCADA-системы, что позволяет существенно снизить объемы утечек газа, эксплуатационные риски и экономический ущерб

Keywords: pressure-based analysis; IoT-supported monitoring; SCADA-based control; leak position estimation; digital pipeline management.

Ключевые слова: Интернет вещей (IoT); SCADA; утечка газа; аналитическая локализация; автоматическое управление.

Введение

Современные системы транспортировки природного газа предъявляют повышенные требования к надежности, безопасности и непрерывности эксплуатации. Особенно актуальной является задача оперативного выявления и локализации аварийных режимов в параллельных газопроводах, где утечки и нарушения целостности трубопровода могут приводить к значительным технико-экономическим потерям [1, 2, 8, 13].

Широкое внедрение цифровых технологий мониторинга, включая беспроводные датчики давления, системы SCADA и платформы Интернета вещей (IoT), позволило обеспечить дистанционное наблюдение за параметрами газопроводов в реальном времени [9, 11, 12,]. Однако практика эксплуатации показывает, что изменения давления в трубопроводах могут быть вызваны как технологическими причинами (изменение режимов потребления, работа компрессорных станций), так и аварийными процессами (утечки газа, разгерметизация). Использование только мониторинговых данных без аналитической интерпретации не позволяет надежно различать эти режимы.

В данной работе предлагается подход к интеллектуальному управлению аварийными режимами в параллельных газопроводах, основанный на синтезе цифрового мониторинга и аналитических газодинамических моделей [4, 7] . Методология направлена на формирование компактного алгоритма принятия решений для диспетчерских центров, включающего идентификацию аварийного режима, аналитическую локализацию места утечки и оптимизацию управляющих воздействий. Предлагаемый подход ориентирован на практическую реализацию в SCADA-системах и обеспечивает снижение аварийных рисков при минимальном увеличении объема вычислений и текстового описания.

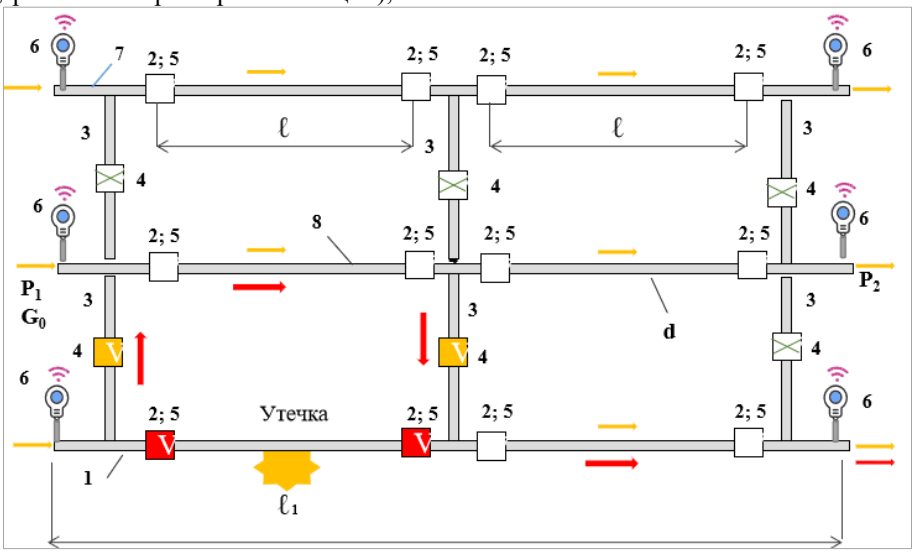

Рисунок 1. Интеллектуальное аварийное управление в параллельных газопроводах

1- поврежденный трубопровод; 2- запорные клапаны с калибровкой по скорости падения давления газа; 3- соединительные трубы параллельных трубопроводов; 4- автоматические запорные клапаны соединительных труб; 5- проводной датчик положения клапана; 6- беспроводной датчик давления; 7,8 - неповрежденные параллельные газопроводы; L - длина газопровода, м; P_1 - входное давление газопровода, Па; P_2 - давление на выходе газопровода, Па; G_0 - начальный массовый расход газопровода; d - диаметр трубопровода, м; ℓ - расстояние между соединительными трубами параллельных трубопроводов, м; ℓ_1 - расстояние от входа поврежденного газопровода до точки утечки, м.

Описание технологической схемы и принципа управления

На рисунке 1 представлена технологическая схема интеллектуального управления аварийными режимами в многолинейных параллельных газопроводах. Схема ориентирована на оперативное выявление утечек, локализацию поврежденного участка и минимизацию потерь газа за счет аналитически обоснованных управляющих воздействий.

Система включает параллельно работающие газопроводы, соединительные трубопроводы, автоматические запорные клапаны и цифровые средства мониторинга. Контроль состояния газопроводов осуществляется с использованием беспроводных датчиков давления, установленных на входных и выходных участках, данные от которых в реальном времени передаются в диспетчерский центр через IoT-платформу[5, 6, 10] .

Ключевым элементом схемы являются клапаны, откалиброванные не по абсолютному значению давления, а по скорости его падения. Такой принцип позволяет надежно различать технологические колебания давления и аварийные процессы, сопровождающиеся резким нарушением газодинамического равновесия. При выявлении аварийного режима происходит синхронное закрытие клапанов, расположенных по обе стороны от предполагаемого места утечки, что обеспечивает быструю изоляцию поврежденного участка.

Соединительные трубопроводы между параллельными линиями обеспечивают возможность перераспределения газового потока. Управление кла-

панами на этих трубопроводах осуществляется автоматически на основе аналитических расчетов, что позволяет стабилизировать режим работы системы без нарушения функционирования исправных газопроводов.

Предложенная компоновка элементов схемы обеспечивает локальный характер аварии, снижает объем выбросов газа и повышает надежность эксплуатации параллельных газопроводов. Интеграция технологической схемы с SCADA-системами позволяет реализовать замкнутый цикл управления, включающий мониторинг, анализ, принятие решения и его автоматическое исполнение.

Аналитический критерий различения аварийного и технологического режимов

Одной из ключевых задач управления параллельными газопроводами является надежное различение технологических и аварийных режимов на основе данных цифрового мониторинга. Изменения давления на входе и выходе трубопровода могут быть обусловлены как нормальными эксплуатационными процессами, так и аварийными явлениями, связанными с утечкой газа. В этой связи в работе предложен аналитический критерий, основанный на газодинамических соотношениях.

Для идентификации режима эксплуатации используется следующая логическая зависимость [3]:

$p(t) \in D \Rightarrow$ аварийный режим,

$p(t) \notin D \Rightarrow$ технологический режим. (1)

где, $D = \dfrac{\varphi - 0.5}{\varphi + 0.5}$ $\varphi = \dfrac{2}{3} + \dfrac{e^{-2\alpha t_1} - 4e^{-2\alpha t_1}}{\pi^2}$

$\alpha = \dfrac{\pi^2 c^2}{2aL^2}$ $p(t) = \dfrac{P_1 - P_1(0,t)}{P_2 - P_2(L,t)}$, p(t) - обобщенная функция, формируемая на основе временных изменений давления на входе и выходе газопровода, а D - область допустимых газодинамических состояний, определяемая паспортными параметрами трубопровода и физическими свойствами транспортируемого газа.

Физический смысл критерия (1) заключается в том, что при технологических режимах изменения давления носят плавный и ограниченный характер, тогда как при аварийных процессах наблюдаются резкие асимметричные отклонения, выходящие за пределы допустимых газодинамических траекторий. Таким образом, критерий учитывает не только абсолютные значения давления, но и характер их изменения во времени.

Предложенный подход не требует установки дополнительных измерительных устройств и может быть реализован в реальном времени в диспетчерских центрах. Использование аналитического критерия позволяет повысить достоверность идентификации аварийных режимов и снизить вероятность ложных срабатываний по сравнению с классическими пороговыми методами.

Определение момента аварии и аналитическая локализация места утечки

После идентификации аварийного режима по критерию (1) следующей задачей является оперативное определение момента начала аварии и локализация места утечки. Данная информация необходима для последующего принятия корректных управляющих решений и минимизации последствий аварии.

Момент аварии t_1 определяется как время, при котором нестационарное возмущение давления, вызванное утечкой, становится достоверно фиксируемым на входе и выходе газопровода. С учетом волнового характера распространения возмущений в газе и принимая скорость распространения давления близкой к скорости звука, момент аварии оценивается выражением:

$$t_1 = \frac{L}{c} \tag{2}$$

где L - длина газопровода, c - скорость звука в транспортируемом газе.

После определения t_1 локализация места утечки осуществляется на основе анализа асимметрии давления на входе и выходе трубопровода. Для этого используется аналитическая зависимость [2,4]:

$$\ell_1 = \frac{L}{2} + L\left[\frac{1 - p(t)}{1 + p(t)}\right] \cdot \varphi$$

$$p(t_1) = \frac{P_1 - P_1(0,t_1)}{P_2 - P_2(L,t_1)} \tag{3}$$

где $P_1(0,t_1)$ и $P_2(L,t_1)$ - давления на входе и выходе газопровода в момент аварии, G_0 начальный расход газа, d — диаметр трубопровода.

Физически утечка приводит к нарушению симметрии распределения давления вдоль трубопровода: давление на входе возрастает, а на выходе уменьшается. Данная асимметрия позволяет восстановить координату утечки ℓ_1 без использования дополнительных датчиков. Предложенный метод применим в реальном времени и ориентирован на практическую реализацию в системах диспетчерского управления.

Определение оптимального времени открытия соединительных трубопроводов

После локализации поврежденного участка газопровода и его изоляции следующей важной задачей является восстановление устойчивого режима работы системы за счет оптимального управления соединительными трубопроводами между параллельными линиями. Неправильный выбор момента открытия соединительных клапанов может привести либо к нарушению режима исправного газопровода, либо к дополнительным перегрузкам компрессорного оборудования.

В данной работе момент открытия клапанов соединительных трубопроводов определяется аналитически с учетом динамических характеристик компрессорной станции. Для этого предлагается следующее выражение [3]:

$$t_2 = t_1 + \frac{1}{\varphi}\ln\left(\frac{1}{C}\right) \tag{4}$$

где t_1- момент аварии, φ - коэффициент сжатия газоперекачивающих агрегатов,

C - постоянная Эйлера.

Физический смысл выражения (4) заключается в обеспечении временной задержки, необходимой для газодинамической адаптации системы после изоляции аварийного участка. Данный интервал времени позволяет предотвратить неконтролируемый переток газа из исправного трубопровода в аварийную зону и одновременно исключить опасное повышение давления на входе поврежденного участка.

Использование аналитически определенного момента t_2 обеспечивает стабилизацию режима работы параллельных газопроводов, снижает нагрузку на компрессорные станции и способствует сохранению непрерывности газоснабжения потребителей.

Выводы

В статье предложен компактный и практически ориентированный подход к интеллектуальному управлению аварийными режимами в параллельных газопроводах на основе интеграции цифрового мониторинга и аналитических газодинамических моделей. Показано, что использование только систем мониторинга давления не обеспечивает достаточной надежности идентификации аварийных процессов без аналитической интерпретации измеренных данных.

Разработан аналитический критерий различения аварийных и технологических режимов, позволяющий повысить достоверность обнаружения утечек газа в реальном времени. Предложен метод определения момента аварии и аналитической локализации места утечки без применения дополнительных датчиков, что существенно снижает сложность и стоимость системы.

Получено выражение для определения оптимального момента открытия соединительных трубопроводов, обеспечивающее стабилизацию режима работы параллельных газопроводов и защиту исправных линий от аварийного воздействия. Предлагаемая методология может быть реализована в диспетчерских центрах и интегрирована в SCADA-системы без значительного увеличения вычислительных затрат.

В целом, результаты работы демонстрируют эффективность аналитически обоснованного подхода к управлению аварийными режимами и могут быть использованы при проектировании и эксплуатации современных газотранспортных систем.

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